GLAST LAT PROCEDURE	Document # **LAT-SS-01345-01**	Date Effective 13 Feb 2003
	Prepared by(s) Kurt Smithgall	Supersedes None
	Subsystem/Office Calorimeter Subsystem	
Document Title **LAT Calorimeter Verification & Environmental Test Plan**		

Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT) Calorimeter

Verification & Environmental Test Plan

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CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
D1	17 January 2003	Initial Draft
01	13 February 2003	Initial Release

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to establish the basic requirements for each LAT CAL component and module as derived from the LAT Program Instrument Performance Verification Plan. It outlines the testing to be performed at the engineering model, qualification, and acceptance test phases.

1.2 SCOPE

The scope of this document illustrates the various testing phases in which each component and completed CAL Module shall experience in order to be considered flight ready. Performance and Science requirements are verified by a combination of testing and analysis at the qualification test level for the Engineering Model (EM), and the Qualification Model (QM). Final flight production CAL Modules are deemed qualified by similarity from the Qualification process and undergo a less intensive test at the acceptance level.

1.3 APPLICABLE DOCUMENTS

Documents and drawings that are applicable to this procedure are listed below.

1.3.1 Documents

GEVS-SE	General Environmental Verification Specification For STS & ELV Payloads, Subsystems, and Components
GSFC-433-MAR-0004	GLAST Mission Assurance Requirements for the Large Area Telescope Phase C/D/E
GSFC-433-RQMT-0005	Electromagnetic Interference (EMI) Requirements Document
LAT-MD-00039	LAT Performance Assurance Implementation Plan
LAT-MD-00228	GLAST LAT CAL, TKR, & DAQ Contamination Control Plan
LAT-MD-00408	LAT Program Instrument Performance Verification Plan
LAT-SS-00115	LAT Mechanical Systems – Level III Specification
LAT-SS-00210	LAT-CAL Subsystem Level IV Specification
LAT-SS-00222	Calorimeter Module Assembly, Test, and Calibration Requirements
LAT-SS-00231	Calorimeter Performance Acceptance Standards and Tests
LAT-SS-00262	Calorimeter Module Assembly and Test Plan
LAT-SS-00778	GLAST LAT Environmental Specification
LAT-SS-01370	Calorimeter Environmental Test Procedure
LAT-SS-01371	Calorimeter Functional Test Procedure
LAT-SS-01372	Calorimeter Qualification Test Procedure
LAT-SS-01373	Calorimeter Acceptance Test Procedure
LAT-TD-00464	GLAST LAT Calorimeter FMEA, RBD, Predictions and CIL
MIL-STD-461E	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
NASA-STD-8739.7	Electrostatic Discharge Control

1.3.2 Drawings

LAT-DS-01224	PEM Assembly Drawing

1.4 DEFINITIONS AND ACRONYMS

1.4.1 Acronyms

AFEE	Analog Front End Electronics of the Calorimeter
CAL	Calorimeter Subsystem of the LAT
CDE	Crystal Detector Element of the PEM
CPT	Comprehensive Performance Test
CsI	Cesium Iodide
DAS	Data Acquisition System
DPD	Dual Pin Diode
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FM	Flight Model
GLAST	Gamma-Ray Large Area Space Telescope
GSE	Ground Support Equipment
LAT	Large Area Telescope
LPT	Limited Performance Test
MECO	Main Engine Cut Off
MGSE	Mechanical Ground Support Equipment
PEM	Pre Electronic Module of the CAL
PIN	Positive Intrinsic Negative
RFU	Release For Use
SFM	Structural Flight Model
SM	Structural Model
TBD	To Be Determined
TBR	To Be Resolved
TEM	Tower Electronics Module
TRR	Test Readiness Review
WOA	Work Order Authorization

1.4.2 Definitions

Acceptance Test	The validation process that demonstrates the hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies and, normally, to provide the basis for delivery of an item under terms of contract
Analysis	A quantitative evaluation of a complete system and/or subsystems by review/analysis of collected data
cm	centimeter
Demonstration	To prove or show, usually without measurements of instrumentation, that the project/product complies with requirements by observation of the results.
Electromagnetic Compatibility (EMC)	The condition that prevails when various electronic devices are performing their functions according to design in a common electromagnetic environment.
Electromagnetic Interference (EMI)	Electromagnetic energy that interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical equipment.

Electromagnetic Susceptibility	Undesired response by a component, subsystem, or system to conducted or radiated electromagnetic emissions.
eV	Electron Volt
Inspection	To examine visually or use simple physical measurement techniques to verify conformance to specified requirements.
kg	kilogram
MeV	Million Electron Volts, 10^6 eV
mm	millimeter
Operate	The ability to withstand the applied environment without malfunction, loss of capability, change of operation state/mode, memory changes or need for outside intervention. Operate is the ability of an instrument to execute all ancillary and housekeeping tasks including self-test, but does not include the ability to take scientific data.
Perform	The ability to execute its science mission or to meet its specified performance. Performance requires that the Operate criteria be met.
Performance Test	The operation of a unit in accordance with a defined operational procedure to determine whether performance is within the specified requirements. Two types of performance tests within this document are the Limited Performance Test (Functional) and the Comprehensive Performance test.
Qualification Test	Tests intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations. Their purpose is to uncover deficiencies in design and method of manufacture. They are not intended to exceed design safety margins or to introduce unrealistic modes of failure.
sec	seconds
Simulation	To examine through model analysis or modeling techniques to verify conformance to specified requirements
Survive	The ability to withstand the applied environment without any permanent loss of performance capability. Survival is required for both powered and unpowered states.
Testing	A measurement to prove or show, usually with precision measurement or instrumentation, that the project/product complies with requirements.
Validation	Process used to assure the requirement set is complete and consistent, and that each requirement is achievable.
Verification	Process used to ensure that the selected solutions meet specified requirements and properly integrate with interfacing products

2 SYSTEM DESCRIPTION

Figure 1 shows the Calorimeter Module in an exploded view. The module consists of the Core Structure, CDEs, Closeout Plates, AFEE boards and Side Panels. The complete assembled and integrated CAL Module shall be the article of test within this document. There shall be two (2) distinct versions of the CAL Module assembled and tested prior to commencement of the flight production models. These are the Engineering and Qualification Models. Upon successful completion of the testing of these two units, the Flight CAL Modules, seventeen (17) in total, shall begin the production and test phase.

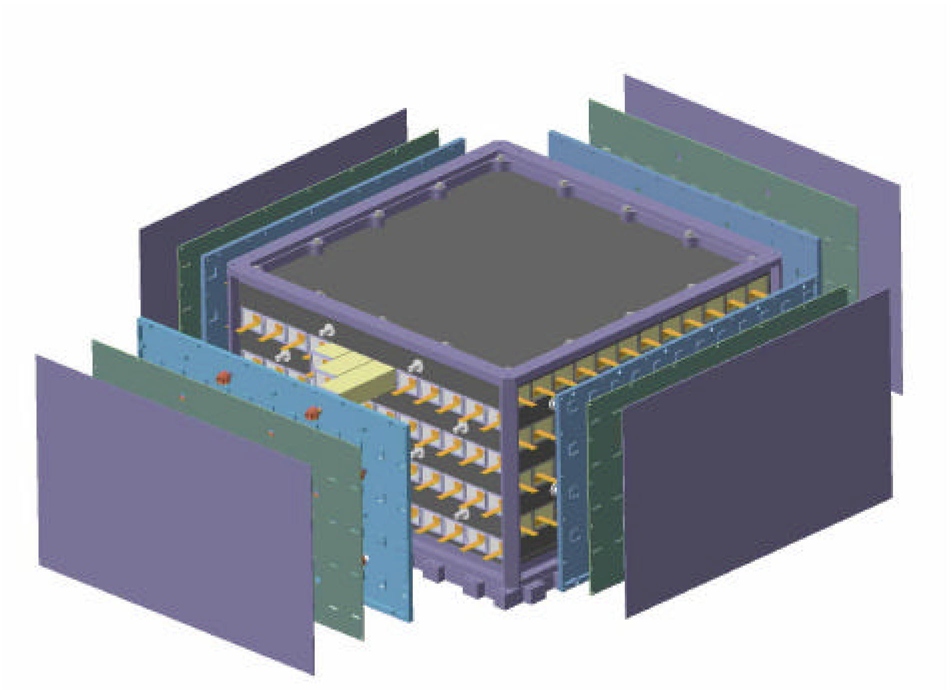

Figure 1: GLAST Calorimeter Module – (Exploded View)

3 VERIFICATION PLAN

3.1 Overview

The LAT CAL Subsystem plans a comprehensive performance verification program in which the performance requirements found in the CAL Subsystem Level IV Specification, [LAT-SS-00210] are verified by a combination of testing and analysis. This verification process is conducted at the component or module level, and then followed through to the integrated subsystem and then later to the LAT system integration levels.

Qualification of the Flight CAL Modules is accomplished through the development and test at qualification levels of two CAL models; the Engineering and Qualification models as well as qualification of a Structural Model and a Structural Flight Model. Those specific tests for the flight units that qualification by similarity to the EM, QM, SM, and SFM modules do not cover shall undergo testing at acceptance levels. This plan covers the verification of the CAL component or module for the Engineering, Structural, Structural Flight, Qualification, and Flight Models.

3.1.1 Objectives

The objectives of the verification program for the GLAST Calorimeter Modules are as follows:

a) Provide assurance that specified science requirements will be met.

b) Provide assurance that the hardware will meet specific performance, interface, and safety requirements.

c) Provide confidence that the instrument modules will survive the environments imposed during the launch and asscent sequence.

d) Determine operating and performance characteristics from simulated mission environments.

3.1.2 General Approach

The general approach for attaining the verification program objectives shall be as follows:

a) The Calorimeter Modules shall be verified by test at the qualification or acceptance test levels. Several models of Calorimeter Modules shall be built and tested. Each subsequent series shall leverage manufacturability and performance characteristics from the previous model towards the goal of flight production.

b) Verification and test shall begin at the subsystem or component level as required/applicable, prior to delivery for integration to the LAT.

c) Calorimeter Module substems shall receive both functional and environmental testing at the qualification or acceptance levels. Flight modules shall either be qualified by similarity or tested to the acceptance levels. (Reference Table 2. Test Requirements for Calorimeter Modules.)

Table 1. (below) summarizes the requirements for the LAT Calorimeter Modules as taken from the LAT CAL Subsytem Specification – Level IV Specification [LAT-SS-00210-D3].

Note: Verification methods are T = Test, A = Analysis, D = Demonstrate, I = Inspect

Table 1: Calorimeter Requirements Verification Matrix

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 5.1.3	The energy resolution shall allow for the measurement of spectral breaks already observed or theoretically predicted from celestial sources.	A	CU	
Level IV - 5.1.3.1	The calorimeter subsystem shall provide a projected CsI area of greater than 16800 cm^2 (TBR) for normally incident particles.	I	LAT	
Level IV - 5.1.4	The calorimeter shall provide imaging capability or physical segmentation to allow the correlation of events in the tracker with energy depositions in the calorimeter.	T	LAT	
Level IV - 5.2.1	The calorimeter subsystem shall consist of a 4x4 array of identical modules.	I	LAT	
Level IV - 5.2.2	The calorimeter modules shall be mounted inside the grid matrix of the LAT GRID subsystem.	I	LAT	
Level IV - 5.2.3	The base of the calorimeter modules shall support the mechanical, thermal and electrical interfaces of the LAT T&DF, ACD and power system components.	I	Module	
Level IV - 5.2.4	The calorimeter modules shall be hodoscopic arrays of CsI(T1) scintillation crystals: eight (8) layers of twelve (12) CsI(T1) scintillation crystals.	I	Module	
Level IV - 5.2.5	PIN photodiodes shall view each end of the CsI scintillation crystals for measurement of the energy depositions in the crystals.	I	CDE	
Level IV - 5.2.6	The CsI crystals shall be processed such that the measurements by the PIN photodiodes at the ends of a crystal provide a measurement of the longitudinal position of the energy deposition in the crystal.	T, A	Module	TEM, PS, Module DAQ
Level IV - 5.2.7	Each calorimeter module shall include analog and digital readout electronics (AFEE) on the four vertical faces at the ends of the CsI crystal array.	I	Module	
Level IV - 5.3.1	The major components of a calorimeter module shall be a mechanical structure, an array of ninety-six CsI(T1) detector elements and four analog front end electronics (AFEE) printed wire assemblies.	I	Module	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 5.3.2.2	The energy resolution (1 sigma) shall be <4% (TBR) for sea-level muons within 6 cm of the central point of the crystal. This measurement shall be deduced from the width of the distribution of the difference in signals of the two large diodes, as given in the following expression: sigma(mu) = sigma(Diff) / sqrt(2), where sigma(mu) is the deduced energy resolution for muons as measured in a single large diode and sigma(Diff) is the measured rms of the distribution of differences P-M in the signal from the large diodes of the Plus (P) and Minus (M) faces. This test may be performed with laboratory electronics of arbitrarily low noise performance.	T, A	CDE	CDE checkout station: CDE muon telescope, CDE DAQ
Level IV - 5.3.3.2	Serial data from the readout electronics shall be merged into a serial message by a tower electronics module (TEM) mounted on the base plate of each module for transfer to the T&DF subsystem.	T	Module	
Level IV - 5.3.3.3	The TEM shall process trigger requests and collect rate and housekeeping monitoring from the CAL AFEE and distribute commands from the T&DF to the AFEE.	T	Module	
Level IV - 5.3.9	Each calorimeter module shall provide a projected CsI area of greater than 1050 cm^2 (TBR) for normally incident particles.	I	Module	
Level IV - 5.3.10	The mass of each calorimeter module shall not exceed 93.25 kg +/- TBR kg (TBR).	T	Module	scale, lifting hardware
Level IV - 5.3.11	The power consumption of each calorimeter module, excluding conditioning, shall not exceed 5.6875 W (TBR).	T	Module	power supply and multimeter
Level IV - 6.1.1	Each calorimeter module shall contain 96 CDE.	I	Module	
Level IV - 6.1.2	The CDE shall contain a CsI(TI) crystal shaped as a rectangular parallelepiped with beveled edges and its surfaces treated to control scintillation light yield at the two ends.	I, T	CDE	
Level IV - 6.1.2.1	The CDE shall contain an optical wrap surrounding the CsI crystal to provide the required optical performance (See Requirement 6.2).	I	CDE	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 6.1.3	The CDE shall have a PIN photodiode assembly bonded to each end of the CsI crystal.	I	CDE	
Level IV - 6.1.4	A flexible printed circuit cable shall be attached to each PIN photodiode to provide electrical connections with the analog front-end electronics board (AFEE).	I	PDA	
Level IV - 6.2.1	The light yield measured by the large PIN photodiode shall be 5000 e-/MeV for energy depositions at the center of the CsI crystal (beginning of life, room temperature (20-25 deg C), measurement techniques as specified in LAT-TD-00381-01).	T	CDE	CDE checkout station: CDE muon telescope, CDE DAQ
Level IV - 6.2.2	The light yield measured by the small PIN photodiode shall be 800 e-/MeV for energy depositions at the center of the CsI crystal (beginning of life, room temperature (20-25 deg C), measurement techniques as specified in LAT-TD-00381-01).	T	CDE	CDE checkout station: CDE muon telescope, CDE DAQ
Level IV - 6.2.3	Copy words from CDE Spec - LA with PIN photodiodes	T	CDE	CDE checkout station: CDE muon telescope, CDE DAQ
Level IV - 6.2.4	The crystal end faces shall be roughened in a random pattern to increase the strength of the bond with the photodiode assembly. The long faces shall be treated to achieve the light asymmetry specification (6.2.3) with the specified wrapping technique (6.2.5).	I	Xtal	
Level IV - 6.2.5	The crystal shall be wrapped with VM 2000 reflective film. The wrap shall be sufficiently tight that the completed CDE can be inserted into its cell within the mechanical structure.	I	CDE	
Level IV - 6.2.6	The CDE shall meet requirements over the qualification temperature range described in 8.1.	I	CDE	CDE checkout station: CDE muon telescope, CDE DAQ
Level IV - 6.2.7	See 6.4.7 (Not defined in Level III)			
Level IV - 6.3	The calorimeter shall be capable of positioning a minimum ionizing energy deposition to less than 1.5 cm (1sigma) (TBR).	T	CU	CDE checkout station: CDE muon telescope, CDE DAQ

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 6.4.1	The CsI(T1) crystals shall be rectangular parallelepipeds with a chamfer on the edges of the long dimension. Figure 1 of LAT-DS-00095 shows the mechanical configuration and tolerances for the crystals.	I	Xtal	
Level IV - 6.4.2	Overall dimensions (mm) of the CsI crystals at 20^{o}C shall be: Length = 333.0 mm, Height = 19.9 mm, Width = 26.7 mm.	I	Xtal	
Level IV - 6.4.3	The tolerance on dimensions (mm) shall be: Length + 0.0, -0.6 mm, Height and Width + 0.0, -0.4 mm	I	Xtal	
Level IV - 6.4.4	The four 333 mm edges of the crystal shall have a chamfer. Chamfer length: 0.7 mm, tolerance +/- 0.20mm, Chamfer angle: 45^{o}, tolerance +/- 5^{o}	I	Xtal	
Level IV - 6.4.5	The signals from each 5 cm diameter photomultiplier tube (PMT) in contact with the two ends of a crystal log shall have a FWHM (Full Width Half Maximum) of less than or equal to 13% with the source at any of eleven (11) evenly spaced points starting 2 cm from one end and finishing 2 cm from the other end of the log. The absolute light yield of the array of crystals shall not vary from crystal to crystal by more than10% from the mean value. This shall be determined by using average of the light yields measured at the eleven sampling points identified in section 6.2.1 of LAT-DS-00095. This average light yield, when corrected for instrumental effects of photo-multiplier gain, shall be the same for all crystals to within 10%.	T	Xtal	Crystal Optical Testing Station
Level IV - 6.4.6	The CsI crystals shall be processed so that the scintillation light is tapered with position. The tapering shall be monotonic along the crystal and such that with the source 2 cm from one end the light collected at the far end is 60 +/- 10% of the light collected by the PMT close to the source. The tapering shall be determined using PMTs exposed to the full crystal end faces.	T	Xtal	Crystal Optical Testing Station

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 6.4.7	The radiation environment (total radiation dose) shall not reduce light output from the CsI crystals by more than 50% at EOL. After irradiation with 10 kRad of gamma-rays from a Cobalt-60 source, the light yield shall not be reduced by more than 50%.	T, A	Xtal	Co60 cell, Crystal Optical Testing Station
Level IV - 6.5.1	The PIN assembly shall hold two PIN photodiodes with a factor of 6 ratio of active areas.	I	DPD	
Level IV - 6.5.2	The photodiodes shall have spectral response compatible with the scintillation spectrum of CsI(Tl).	A	DPD	
Level IV - 6.5.3	The photodiodes shall have photo sensitivity greater than 0.33 A/W at 540 nm.	T	DPD	
Level IV - 6.5.4	The photodiodes shall have dark current of less than 10nA for the large diode and 3.0 nA for the small diode at 20 ^{o}C.	T	DPD	Keithley current meter. Lot sample testing.
Level IV - 6.5.5	The photodiodes shall have terminal capacitance of less than 90 pF for the large diode and 15 pF for the small diode at 1Mhz with 70V reverse bias.	T	DPD	HP capacitance meter. Lot sample testing.
Level IV - 6.5.6	The photodiodes shall have full depletion at 70V.	T	DPD	HP capacitance meter. Lot sample testing.
Level IV - 6.5.7	The photodiode carrier shall be 22.3 (+/-0.2) mm x 15.0 (+/-0.2) mm x 1.8 (+/-0.2) mm.	I	DPD	micrometer
Level IV - 6.5.8	The small PIN photodiode shall have active area greater than 25 mm^2. The large PIN photodiode shall have active area greater than 150 mm^2.	I	DPD	micrometer
Level IV - 7.1.1	The GLAST coordinate system is a right-handed coordinate system with the Y-axis parallel to the solar panel axis, the Z axis normal to the planes of the TKR Si trays, CAL crystals, and Grid *(i.e.*, parallel to the "bore sight"), and the X axis mutually perpendicular to Y and Z. The details shall be in accordance with LAT-TD-00035.	I	LAT	
Level IV - 7.1.2	Total mass of a calorimeter module shall not exceed 93.25 kg +/- TBR kg (TBR).	T	Module	scale, lifting hardware

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Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 7.1.3	The calorimeter module shall comply with the geometry specified in Table 2. The total height of the calorimeter and its mechanical mounting structure shall not exceed 223.8 mm.	I	Module	
Level IV - 7.1.4	The CAL module structure shall provide the mechanical interface to the LAT grid as specified in ICD LAT-SS-00238. The CAL module structure shall provide the nominal positioning, support and mounting interfaces for all subsystem components. The CAL module structure shall support the Power Supply module and TEM as specified in ICD TBD.	A, I	Module	
Level IV - 7.1.5	The CAL structure shall provide adequate venting as described in document TBD.	A	Mech Struct	
Level IV - 7.1.6	Purging with dry nitrogen shall be required if the relative humidity of the environment exceeds 50%.	I		
Level IV - 7.2	The CAL structure shall provide and maintain the positional integrity of all components that it supports. The structure shall maintain the operational stability of the positions of all instrument components under load.	T, A	QM	
Level IV - 7.2.1	The CAL structure baseplate is integral to the strength and stability of the LAT GRID. The mechanical structure shall provide a minimum fundamental frequency greater than 100 Hz to a CAL module, isolated from other systems.	A	QM	NASTRAN

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 7.2.2.1	The CAL mechanical structure shall be able to withstand the different load events without yielding, failing or exhibiting deformations that can influence the performance of the CAL modules or any other system or sub-system. Any point of the mechanical structure shall not displace by more than 0.5mm under a +/-12g static load, applied along X or Y axis independently, to avoid interaction with the grid walls. Any point of the top of the mechanical structure shall not displace by more than 0.5mm under a +/- 12g static load applied along the Z axis. To minimize mechanical loads on the TEM boxes, attached below the CAL modules, no point of the bottom plate of the mechanical structure shall displace by more than 0.5mm under a +/- 12g static load applied along the Z axis.	T	QM	
Level IV - 7.2.2.2	The CAL mechanical structure shall be stiff enough in the X and Y directions to keep the difference between the RMS displacements between any two points of the side panels below 0.25 mm, under random vibration with qualification levels. The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the top of the structure below 0.5 mm, under random Vibration with qualification levels. The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the bottom plate below 0.25 mm, under random vibration with qualification levels. The levels for random vibration are defined in Table 3.7-3 of LAT-SS-00241-D2.	T	QM	Random Vibe Table
Level IV - 7.2.2.3	Over a temperature change of 10 degrees C, the mechanical structure shall not distort more than: 0.25mm between any two points of the side panels, 0.5mm between any two points of the top of the structure and 0.25 mm between any two points of the bottom plate.	A	Module	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 8.1	The LAT thermal control system shall maintain the CAL components within the operating, test and survival temperatures shown in Table 3.8-1 of LAT-SS-00241-D2.	T, A	LAT	thermal balance facility
Level IV - 8.2	The temperature of each AFEE board, and the top and bottom plate of the calorimeter shall be monitored by separate temperature sensors with an accuracy of +/- 0.5 ^{o}C. These sensors shall read out once per minute. The housekeeping software shall monitor the temperature of the 96 sensors and issue a warning if any sensor goes out of TBD range. If any sensor goes out of the broader TBD range, the power to the calorimeter module associated with the sensor will be turned off and a red flag issued for the CA L/LAT??.	T, I	LAT	
Level IV - 9.1	The GCFE shall perform spectroscopic measurements over a range from 0.4 MeV to 100 GeV. Each GCFE ASIC shall service one crystal end. The dynamic range shall be divided into two independent signal chains, one for the low energy range, one for the high energy range.	T	CU	SLAC, CU DAQ
Level IV - 9.1.1.1	The low energy charge amplifier shall process energy depositions in the 2 MeV to 1.6 GeV range. The characteristics of the inputs to the low energy range are summarized in Table 9.3.	T	CU	
Level IV - 9.1.1.2	The low energy range amplifier shall receive a charge of ~5000 e-/MeV with time constants defined by CsI(T1) scintillation constants. These are identified in Table 9.4.	T	AFEE	
Level IV - 9.1.1.3	The low energy charge amplifier shall meet performance specs when attached to PIN photodiode with capacitance ≤ 90 pF (TBR).	T	AFEE	
Level IV - 9.1.1.4	The low energy charge amplifier shall meet performance specs when attached to PIN photodiode with dark or leakage current ≤ 10 nA (TBR) at a temperature of 20 degrees C.	T	AFEE	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.1.5	The low energy front end shall recover from a x1000 overload within 100 μsec (TBR). Recovery is defined as signal amplitude below the accept or zero-suppression threshold.	T	AFEE	
Level IV - 9.1.1.6	The gain of the low energy channels shall be adjustable by at least a factor of 2 in steps of approximately 10%-25%.	T	AFEE	
Level IV - 9.1.2.1	The high energy charge amplifier shall process energy depositions in the 100 MeV to 100 GeV range. The characteristics of the inputs to the high energy range are summarized in Table 9.3.	T	CU	SLAC, CU DAQ
Level IV - 9.1.2.2	The high energy range amplifier shall receive a charge of ~800 e-/MeV (TBR) with time constants defined by CsI(T1) scintillation constants. These are identified in Table 9.4.	T	AFEE	
Level IV - 9.1.2.3	The high energy charge amplifier shall meet performance specs when attached to PIN photodiode with capacitance ≤ 15 pF (TBR).	T	AFEE	
Level IV - 9.1.2.4	The high energy charge amplifier shall meet performance specs when attached to PIN photodiode with dark or leakage current <= 3 nA (TBR) at a temperature of 20 ^{o}C.	T	AFEE	
Level IV - 9.1.2.5	The gain of the high energy channels shall be adjustable by at least a factor of 2 in steps of approximately 10%-25%. An additional gain setting shall be used for ground liveness testing.	T	AFEE	
Level IV - 9.1.3	The outputs of the charge sensitive preamps shall be shaped with two differing time constants, fast shaping for trigger discriminators and a slower shaping for energy measurements. The slow shaped signals of each charge amplifier are each divided into two energy domains.	T	AFEE	
Level IV - 9.1.3.1	The low energy fast shaped signals shall peak at 0.5 +/- 0.2 μsec.	T	AFEE	
Level IV - 9.1.3.2	The low energy fast shaping amplifier shall support the lowest ~ 25% of low energy range, i.e. nominally 400 MeV maximum energy.	T	AFEE	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.3.3	The high energy fast shaped signal shall peak at 0.5 +/- 0.2 μsec.	T	AFEE	
Level IV - 9.1.3.4	The high energy fast shaping amplifier shall support the entire low energy range, i.e. nominally 100 GeV maximum energy.	T	AFEE	
Level IV - 9.1.3.5	The low energy fast shaped signal shall peak at 3.5 +/- 0.5 μsec. All ASICs shall have the same peaking time +/- 0.2 μsec.	T	AFEE	GSE software and TEM. Software will vary time between event trigger and peak hold, mapping out shaped pulse.
Level IV - 9.1.3.6	The LEX1 amplifier of the low energy channel shall process the entire low energy charge amplifier range, i.e. nominally 1.6 GeV maximum energy.	T	AFEE	
Level IV - 9.1.3.7	The LEX8 amplifier of the low energy channel shall process the lowest eighth of the low energy charge amplifier range, i.e. nominally 200 MeV maximum energy.	T	AFEE	
Level IV - 9.1.3.8	The HEX1 amplifier of the high energy channel shall process the entire high energy charge amplifier range, i.e. nominally 100 GeV maximum energy.	T	AFEE	
Level IV - 9.1.3.9	The HEX8 amplifier of the high energy channel shall process the lowest eighth of the high energy charge amplifier range, i.e. nominally 12.5 GeV maximum energy.	T	AFEE	
Level IV - 9.1.4	Each of the four slow shaped amplifiers (LEX8, LEX1, HEX8 and HEX1) shall have track and hold (T&H) circuits designed to hold the peak amplitude of the shaped outputs for amplitude measurements using external ADCs. The timing of the hold signal to capture the peak shall be controlled externally.	T	AFEE	
Level IV - 9.1.4.1	When the hold signal is not active, the T&H circuit shall track the amplitude of the shaped input signal. Thus, adjustment of the hold signal timing relative to the energy deposition shall permit mapping of the pulse shape of the shaper output.	T	AFEE	GSE software and TEM. Software will vary time between event trigger and peak hold, mapping out shaped pulse.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.4.2	The T&H circuit shall respond to an externally generated hold signal by capturing the amplitude of the shaped signal at the time of the hold. Hold aperture time shall be less than 50 nsec.	T	AFEE	GSE software, TEM and oscilloscope. Software will perform charge injection testing at a constant input charge, and perform readout based upon received trigger requests. Scope will verify aperture jitter of hold signal.
Level IV - 9.1.4.3	The T&H circuit shall be capable of holding a constant signal amplitude for >100 μsec with less than 0.1% droop for a signal amplitude dynamic range of 500 (TBR).	T	AFEE	GSE software and TEM. For test charge injection, and 4 channel readout mode, the readout order will be changed and the magnitude of each channel's signal will be mapped vs. readout order.
Level IV - 9.1.5	The maximum non-linearity in each of the four ranges: LEX8, LEX1, HEX8 and HEX1 shall be 1% of full range.	T	AFEE	GSE software and TEM. GSE will step through AFEE board DAC settings and perform charge injection. Non-linearity of AFEEs vs. DAC value will be plotted.
Level IV - 9.1.6	An analog multiplexer shall present one of the four T&H signals to an output buffer for external amplitude measurements with an ADC. The analog multiplexer shall be controlled by energy range selection logic as described in 9.1.7.	T	AFEE	GSE software and TEM. The software will separately enable autoranging in the GCFE low energy then high energy inputs. Input charge injection will be varied and correct readout order will be checked.
Level IV - 9.1.7	An output buffer shall accept the output of the analog multiplexer and driver the load of an external ADC.	T	AFEE	GSE and Software. If the GCFE exhibits good integral linearity of a ramped and digitized signal, then the GCFE has a buffer of sufficient drive strength.
Level IV - 9.1.7.1	The external buffer shall adjust the voltage range of the analog multiplexer to match the input voltage range of the external ADC.	T	AFEE	GSE and Software. Using test charge injection, the overlap regions of the digitized channels will be examined for sufficient overlap.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.8	Energy range selection logic shall control which of the four T&H energy ranges is selected in the analog multiplexer and presented to the output for digitization by the ADC.	T	AFEE	GSE software and TEM. The software will separately enable autoranging in the GCFE low energy then high energy inputs. Input charge injection will be varied and correct readout order will be checked.
Level IV - 9.1.8.1	Range selection discriminators shall test the output of the four T&H ranges to determine which of the ranges have been saturated by the energy deposition in the crystal. Saturation is defined as the amplitude at which the input signal enters a non-linear region.	T	AFEE	GSE software and TEM. The software will separately enable autoranging in the GCFE low energy then high energy inputs. Input charge injection will be varied and correct readout order will be checked.
Level IV - 9.1.8.2	The results of the range selection logic, i.e. the multiplexer setting, shall be transmitted to external logic for inclusion in the event readout with the associated ADC value.	T	AFEE	GSE software and TEM. The software will disable autoranging in the GCFE, set a particular range readout order in the GCFE, perform charge injection readout, and examine the data for proper channel bits.
Level IV - 9.1.8.3	In auto range selection mode, the range selection discriminators shall be tested to select the T&H output with the lowest energy range (highest gain) that is not saturated and set the analog multiplexer to this T&H output.	T	AFEE	GSE software and TEM. The software will separately enable autoranging in the GCFE low energy then high energy inputs. Input charge injection will be varied and correct readout order will be checked.
Level IV - 9.1.8.4	In commanded range selection, the selection logic shall use a pre-loaded (via command input) range and set the multiplexer to that T&H output.	T	AFEE	GSE software and TEM. The software will disable autoranging in the GCFE, set a particular range readout order in the GCFE, perform charge injection readout, and examine the data for proper channel bits.
Level IV - 9.1.8.5	In either the auto range or commanded range selection mode, it shall be possible to sample all four T&H outputs in sequence. The sequence shall start at the autoranged or commanded range and increment (modulo 4) through the four ranges. The increasing order shall be LEX8, LEX1, HEX8 and HEX1.	T	AFEE	GSE software and TEM. Software will enable GCFEs for 4 range readout, and then perform test charge injection. Returned data bits will be examined for 4 range data.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.9.1	The amplitude of the LEX8 output shall be compared with a programmable threshold, the accept lower level discriminator, to identify CsI crystals with measurable energy depositions. This crystal-accept signal shall be transmitted to external logic for determination of crystals to be included in the event readout message.	T	AFEE	GSE software and TEM. Software will vary the log accept DAC value and vary the charge injection about this level. Returned data will be examined for log accept bit setting vs. Log accept DAC setting and charge injection.
Level IV - 9.1.9.2	The accept discriminator level shall be adjustable by command to the ASIC with adjustment resolution of ~ 0.25 MeV over the lowest approximately 10% of the LEX8 energy range.	T	AFEE	GSE software and TEM. Software will vary the log accept DAC value and vary the charge injection about this level. Returned data will be mapped for Log accept DAC setting and charge injection energy.
Level IV - 9.1.10	The outputs of the two 0.5 μsec shaping amplifiers (FHE and FLE) are connected to discriminators. The two outputs of the trigger discriminators logic are provided to external logic which forms the calorimeter trigger request inputs to the GLAST trigger system.	T	AFEE	GSE software and TEM. Software running in muon calibration mode will verify that no logs are missing muon data.
Level IV - 9.1.10.1	The variation in time of the leading edge of the trigger output from the time of energy deposition shall be less than +/- 0.2 μsec.	T	AFEE	GSE software, TEM and oscilloscope. Software will perform charge injection and scope will be used to look at trigger request timing.
Level IV - 9.1.10.2	Each of the two trigger signals shall be individually enabled or disabled by command input to the ASIC.	T	AFEE	GSE software and TEM. Running in muon mode, software will alternately disable low energy and high energy GCFE triggers and the TEM will be set to only recognize triggers from the disabled energy range triggers. Software will check that no trigger requests are forwarded by the TEM.
Level IV - 9.1.10.3	The low energy trigger (FLE) discriminator level shall be adjustable by command input to DACs inside the ASIC. Two adjustment ranges shall be provided: lowest energies (<~ 60 MeV) with ~ 1 MeV resolution and moderate energies (<~ 400 MeV) with ~ 5 MeV resolution.	T	AFEE	GSE software and TEM. Running in muon mode, the FLE DACs will be set to a value and then event data will be collected. The resulting spectrum will be analyzed for correct low-energy cutoff.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.10.4	The high energy trigger discriminator level shall be individually adjustable by command input to DACs inside the ASIC. The range of adjustment shall include the lowest ~25% of the high energy charge amplifier range (<~ 25 GeV) and have ~ 200 MeV resolution.	T	AFEE	GSE software and TEM. Running in muon mode, the FHE DACs will be set to a value and then event data will be collected. The resulting spectrum will be analyzed for correct low-energy cutoff.
Level IV - 9.1.11	The GCFE ASIC shall accept a precision calibration voltage from an external DAC as a reference voltage for a calibration charge injection system.	T	AFEE	GSE software and TEM. Run charge injection calibration.
Level IV - 9.1.11.1	The test charge injection system shall be capable of testing the entire dynamic range of the GCFE ASIC.	T, D	AFEE	GSE software and TEM. Run charge injection calibration. The resulting data will be equated to equivalent energy input levels.
Level IV - 9.1.11.2	The charge injection system shall provide input signals to the charge amplifier with time characteristics similar to the CsI light collection.	T	AFEE	Oscilloscope. The time to peak of the shaped signal due to charge injection will be compared to CsI generated time to peak.
Level IV - 9.1.11.3	External signals shall cause the injection of charge into the charge amplifiers. Commandable configuration logic shall cause the injection to occur into either or both of the low energy and high energy charge amplifiers.	T	AFEE	GSE software and TEM. Perform charge injection separably for the low energy inputs and the high energy inputs.
Level IV - 9.1.11.4	The high energy charge amplifier shall provide a test gain to be used in ground aliveness test with cosmic muons. The test gain shall increase the nominal gain by a factor of approximately 10. The test gain configuration is pre-selected by command input to the ASIC.	T	AFEE	GSE software and TEM. Running in muon mode with GCFE configuration bits set for largest high energy preamp gain. Analyze resulting spectrum for muon peak.
Level IV - 9.1.12	The GCFE ASIC operation configuration shall be selected by commands received via serial command system that is compatible with GLAST standard command protocols.	T, D	AFEE	
Level IV - 9.1.12.1	Each GCFE ASIC shall respond to its own command address, which shall be programmed via input address pins.	T, D	AFEE	GSE software and TEM. As part of hardware checkout, software will read and write to each individual GCFE chip.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.12.2	The GCFE shall decode and recognize predefined command functions and internally route associated command function data to the appropriate configuration register.	T, D	AFEE	GSE software and TEM. As part of hardware checkout, software will read and write to each individual GCFE chip. Register read backs will verify write operation.
Level IV - 9.1.12.3	The GCFE shall be capable of reporting its operating configuration to the external data system when requested via configuration read back command requests.	T, D	AFEE	GSE software and TEM. Complete read back of known GCFE register states will be performed.
Level IV - 9.1.13	The GCFE ASIC shall capture and read out event amplitudes under the control of external acquisition control timing signal. The external timing shall control the capture of the peak pulse amplitude in the T&Hs, the range selection and readout of the range and crystal accept bits, the selection and readout of sequential ranges and the final reset of the ASIC to idle tracking configuration. The timing of this sequence shall be controlled with the external signal; the control logic and decision making shall be internal to the ASIC.	T	AFEE	GSE software and TEM. Running in muon mode will verify stated operations.
Level IV - 9.1.14.1	The equivalent noise (RMS) on the low energy slow shaped signal paths (LEX8, LEX1) shall be less than 2000 e-. The equivalent noise (RMS) on the low energy fast shaped signal path (FLE) shall be less than 3000 e-.	T	AFEE	GSE software and TEM. For slow shaper noise, charge injection will be performed at a few different charge injection levels, dwelling at a level for a minimum of 500 injections. Resulting spectrum FWHM values will determine the noise. For fast shaper noise, the trigger DAC will be set to a low value and the charge injection DAC will be stepped in value, minimum of 500 injections per step, around the trigger DAC setting. The spectrum of number of triggers per step will be examined to determine fast shaper noise.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.14.2	The equivalent noise (RMS) on the high energy slow shaped signal paths (HEX8, HEX1) shall be less than 2000 e-. The equivalent noise (RMS) on the high energy fast shaped signal path (FHE) shall be less than 10000 e-.	T	AFEE	GSE software and TEM. For slow shaper noise, charge injection will be performed at a few different charge injection levels, dwelling at a level for a minimum of 500 injections. Resulting spectrum FWHM values will determine the noise. For fast shaper noise, the trigger DAC will be set to a low value and the charge injection DAC will be stepped in value, minimum of 500 injections per step, around the trigger DAC setting. The spectrum of number of triggers per step will be examined to determine fast shaper noise.
Level IV - 9.1.14.3	The output of the buffer amplifier for each of the four amplifier ranges shall be monotonically increasing with charge input over the top 99.9% of the energy range. The integral non-linearity shall be less than +/- 0.5% of full scale. This is the deviation of the best fit straight line from the measured amplitudes over the top 99% of the energy range.	T	AFEE	GSE software and TEM. Charge injection will be used to map the integral non-linearity of the sample-and-hold and output buffer amplifier.
Level IV - 9.1.14.4	The signal acquisition and processing time for a single energy range shall be less than 100 μsec. The goal shall be 20 μsec.	T	AFEE	GSE software, TEM and oscilloscope. The readout time of the calorimeter will be measured between the start of a trigger event until all data is transferred to the TEM. That is the signal acquisition and processing time of the calorimeter.
Level IV - 9.1.15.1	The performance specifications of the GCFE ASIC shall be achieved over the operational temperature range of -10 to +35 degrees C.	T, A	AFEE	GSE software, TEM and thermal cycling facility. Standard calibration tests will be run over full temperature range.
Level IV - 9.1.15.2	The GCFE ASIC shall be capable of meeting its performance specifications after indefinite storage in the temperature range of –20 to 40 degrees C.	T, A	AFEE	GSE software, TEM and thermal cycling facility. Standard calibration tests will be run following powered off storage at maximum and minimum temperatures..

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.1.15.3	The performance of the ASIC shall be tested over the qualification temperature range of –30 to 50 degrees C. It shall survive testing over this range and meet performance specifications when returned to the operational temperature range.	T	AFEE	GCFE ASIC Test Board and GCRC ASIC Test Board. ASICs will be tested over the stated temperature range and again back at room temperature.
Level IV - 9.1.15.4	The GCFE ASIC shall be insensitive to latchup for LETs <8 MeV/(mg/cm^2).	T, A	AFEE	The GCFE ASIC will be tested at a heavy ion beam facility for latchup and register memory loss (SEU).
Level IV - 9.1.15.5	The GCFE ASIC shall meet its performance specifications after a total radiation dose of 10 kRad.	A	AFEE	The GCFE ASIC will be irradiated at a Co60 source to 10k Rad and tested for performance.
Level IV - 9.1.16	The GCFE ASIC shall support one CsI crystal end.	I	AFEE	
Level IV - 9.1.16.1	The GCFE ASIC shall be mounted in a quad flatpack carrier with square footprint of size < 15 mm (TBR).	I	AFEE	micrometer
Level IV - 9.1.16.2	The GCFE carrier height shall be less than or equal to 3 mm.	I	AFEE	micrometer
Level IV - 9.1.17	The GCFE ASIC power consumption shall be less than 6 mW per CsI crystal end.	T	AFEE	GCFE Test board. The GCFE ASIC will be tested for power draw at the readout event rate of 1000 events per second.
Level IV - 9.2.1.1	The ADC shall be a 12 bit ADC.	I	AFEE	
Level IV - 9.2.1.2	The average differential non-linearity of the ADC shall be less than 0.25 least significant bit.	T	AFEE	ADC Test board. A sampling of the ADCs will be tested for differential nonlinearity.
Level IV - 9.2.1.3	The maximum non-linearity of the ADC shall be 0.5% of full range.	T	AFEE	ADC Test board. A sampling of the ADCs will be tested for integral non-linearity
Level IV - 9.2.1.4	The ADC shall perform a full conversion in less than 10 microseconds for all input values.	T	AFEE	GSE software, TEM and oscilloscope. A sample ADC on the EM Cal will be probed to verify conversion time .

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.2.1.5	The ADC shall convert signal between 0 and an applied reference voltage. The applied reference voltage shall be between 2.0 and 3.0 Volts.	T	AFEE	GSE software, TEM and oscilloscope. With charge injection near full scale, it will be verified that an analog signal in the 2 volt range is digitized with the correct resulting data value.
Level IV - 9.2.1.6	The ADC shall use less than 5 mW in quiescent mode and less than 8 mW during conversions.	T, A	AFEE	ADC Test board. The ADC power draw will be monitored running at 1000 conversions per second.
Level IV - 9.2.1.7	The ADC shall not be taller than 3mm and its footprint shall be less than 13mm by 13mm.	I	AFEE	micrometer
Level IV - 9.2.1.8	The ADC shall operate at a voltage of 3.3 Volts.	T, A	AFEE	Data sheet of ADC will be examined.
Level IV - 9.3	The dead time associated with the capture and measurement of the energy depositions shall be less than 20 μsec.	T, A	AFEE	GSE software, TEM and oscilloscope. The readout time of the calorimeter will be measured between the start of a trigger event until all data is transferred to the TEM. That is the signal acquisition and processing time of the calorimeter.
Level IV - 9.4.1	Each AFEE board shall hold the GCFEs, ADCs, GCRCs, a DAC (digital to analog converter for calibrations), a temperature sensor and all the components associated electronics. The AFEE boards shall also support whatever additional electronics or sensors are deemed necessary in the location of the AFEE boards.	I	AFEE	
Level IV - 9.4.2	There shall be two types of AFEE boards, named X-boards and Y-boards for the direction of the crystals they service. The two X (Y) boards are then separated into a –X (-Y) and +X (+Y) boards depending on which side of the calorimeter they service. The +X and –X boards shall be identical except for a hardwired control (jumper) that selects whether a board services the + or – face. The same rule applies for the Y boards.	I	AFEE	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.4.3	Each AFEE board shall service 48 crystal ends. These crystal ends are arranged in 4 layers of 12 crystals. The crystal pitch is ~ 28 mm, the layer pitch is ~ 42 mm. The AFEE layout shall minimize the connection distance between the PIN diode and the GCFE. The –X and –Y boards shall have the channel number within a row increasing from right to left, the +X and +Y boards shall have the channel number within a row increasing from left to right. Left and right are determined by looking from the outside of a board with the Z-axis pointed up.	I	AFEE	
Level IV - 9.4.4	Each crystal end shall connect to the GCFE with a polyimide cable fed through a hole in the AFEE board. The hole for the polyimide cable shall be at least 8 mm by 2 mm. A bending radius of 1 mm is allowed in the corners of the holes. The polyimide cable shall be connected to the AFEE boards using a space qualified connection.	I	Module	
Level IV - 9.4.5	Each AFEE board is provided with two voltages: one 3.3 V source to operate the AFEE board itself and one high voltage in the negative 50-100 volt range to bias the PIN diodes. The regulations of these voltages shall not happen on these boards but the boards shall filter these voltages appropriately.	I	Module	
Level IV - 9.4.6	The AFEE board shall communicate to the Tower Electronics Module (TEM) through Low Voltage Differential Signaling (LVDS). No common ground shall span the connection.	I	AFEE	
Level IV - 9.4.7	Each AFEE board shall have maximum dimensions of 341 mm by 341 mm. The maximum thickness of the board shall be 2 mm. The maximum thickness of the board and its components shall be 8mm. No component shall be raised more than 3mm from either surface of the board.	I	AFEE	micrometer

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.4.8	Each AFEE board shall be supported around its perimeter and with posts traversing the board. There shall be 10 posts passing through the board in rows of 2 or 3 posts. The rows of posts shall be located half way between the rows of PIN diode interface holes. The diameter of the hole in the AFEE boards for the posts shall be TBD mm. No component shall be located within TBD mm of the hole. No trace on the board shall be within TBD mm of the hole. No component shall be located within TBD mm of the outside perimeter of the AFEE board. No trace on the board shall be within TBD mm of the perimeter of the board.	I	AFEE	
Level IV - 9.4.9	Each AFEE board shall not use more than 1.25 Watts of the 3.3 V voltage line. Each AFEE board shall not use more than 0.001 Watts of the 50-100 V voltage line.	T, A	AFEE	GSE software, TEM, ammeter, voltmeter. The software will perform event readout at the rate of approx. 1000 events per second. The current draw of the AFEE power supply lines will be measured. The small current draw of the 50-100 V line will have to measured as the voltage drop across a high value resistor.
Level IV - 9.4.10.1	The performance specifications of the AFEE shall be achieved over the operational temperature range of –10 to +35 degrees C.	T, A	AFEE	GSE software, TEM and thermal cycling facility. The AFEE board will run calibration cycles over the stated temperature range.
Level IV - 9.4.10.2	The AFEE shall be capable meeting its performance specifications after indefinite storage in the temperature range of –20 to +40 degrees C.	T, A	AFEE	GSE software, TEM and thermal cycling facility. The AFEE board will run calibration cycles following storage at the stated temperatures..
Level IV - 9.4.10.3	The performance of the AFEE shall be tested over the qualification temperature range of –30 to +50 degrees C. It shall survive testing over this range and meet performance specifications when returned to the operational temperature range.	T, A	AFEE	GSE software, TEM and thermal cycling facility. The AFEE board will run calibration cycles over the stated temperature range.
Level IV - 9.4.11	The AFEE board shall be grounded to the calorimeter structure per LAT document LAT-SS-00272-D1, LAT Grounding and Shielding Plan.	T	Module	Multimeter.

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 9.4.12	Each AFEE board shall be constructed such than an electrical or electronic failure of one board does not affect any of the other three boards of the same calorimeter module, or the two provided voltages.	A	AFEE	FMEA
Level IV - 9.4.13	Each AFEE board shall be coated with conformal coating per specification TBD.	I	AFEE	
Level IV - 9.5	The calorimeter shall provide a prompt (within 2 μs of an event) high-energy trigger signal with a detection efficiency of 90% (TBR) for 50 GeV gamma rays entering the calorimeter from the LAT field of view with a trajectory which traverses at least 8 RL of CsI.	T	CU	
Level IV - 9.6	The AFEE shall interface to the T&DF system using flexible printed circuit cables, which attach to the TEM mounted on the CAL baseplate. A separate cable shall attach the AFEE to the power system also mounted on the CAL baseplate (TBR).	I	Module	
Level IV - 9.7.1 (This is being moved to 9.1)	The maximum charge delivered to the input of the GCFE ASIC in each gain range shall comply with the following table, under the assumption of the nominal values for light yield in the photodiodes (Requirements 6.2.1 and 6.2.2) and amplifier ranges (Requirements 9.1.3.6 to 9.1.3.9). Range pC at GCFE Input LEX8 .16 LEX1 1.3 HEX8 1.6 HEX1 13	T	AFEE	
Level IV - 10	The Calorimeter Data System functionality shall reside in the Calorimeter Controller, located in the Tower Electronics Module. This functionality and the CAL AFEE to TEM interface requirements are specified in LAT-SS-00467.	T, I	Module	
Level IV - 11.1	All components shall be designed to withstand the induced static, random vibration and acoustic loads associated with a Delta II launch environment. These loads are defined in section 6.1 of the LAT MPS document and are derived from the Delta II LV Payload Planner's Guide.	T, A	QM	NASTRAN, FEM, random vibe facility, GSE cables, computers, power supply

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 11.2	All components shall be designed to withstand the pressure profile associated with the Delta II launch. This profile is defined in Figure 6.7-1 of the LAT MPS document and is derived from the Delta II LV Payload Planner's Guide.	T, A	QM	
Level IV - 11.3	The CAL components shall be designed to operate in a low earth orbit environment.	T, A	QM	
Level IV - 11.4	The instrument subsystems shall be designed to operate in a low earth orbit environment.	T, A	QM	
Level IV - 11.5	Critical systems shall be immune to SEEs. Critical systems are those that can cause permanent loss of mission in the event of a single failure.	T, A	QM	
Level IV - 11.6	All electronics shall be able to power up from an initial temperature of -30 ^{o}C and subsequently transition into their other operational modes/states.	T, A	QM	thermal chambers, GSE cables and computers, power supply
Level IV - 12	The Calorimeter shall provide the functionality required for the SI to perform operations in the sky survey, pointed observation and safe modes of operation. These specific requirements can be found in the GLAST Mission System Specification (MSS), Section 3.1.15, Modes of Operation. The Calorimeter shall meet the load shedding requirements of the fault protection functions on the spacecraft that are identified in the SI/SC IRD, Section 3.2.7, Fault Protection.	T	LAT	
Level IV - 13.1	CAL modules shall have ground-support equipment that will allow for stand-alone operation, test and data analysis.	T, D	Module	
Level IV - 13.2	CAL module GSE shall be supported by TEM and T&DF simulators provided by the T&DF subsystem designers.	T, D	Module	
Level IV - 13.3	Workstations or personal computers associated and provided with the CAL subsystem shall have Ethernet connectivity with appropriate software to share data files and electronic messages with other nodes on the I&T local area network.	T, D	Module	

Requirement #	Summary	Verification Method	Verification Level	GSE
Level IV - 13.4	All module components shall undergo functional, environmental and interface testing prior to module integration and test in order to verify their individual functional and performance requirements.	I	All	
Level IV - 14.1	The Calorimeter shall be capable of tolerating temperatures of 20-25^{o}C in air, in any operational mode. This is the expected temperature range of the controlled environment in the integration and test facilities.	I	LAT	
Level IV - 14.2	The Calorimeter shall be capable of tolerating relative humidity in the range 35%-50%, in any operational mode. This is the expected humidity range of the controlled environment in the integration and test facilities.	I	LAT	

Table 2 Calorimeter Requirements Verification Matrix

HARDWARE						MECHANICAL							ELECTRICAL					THERMAL				OTHER					
MODEL	LEVEL	COMPONENT (ITEM)	QUANTITY	TYPE	SUPPLIER	STATIC LOAD	SINE BURST	SINE SWEEP	RANDOM VIB	ACOUSTIC	PRESSURE PROFILE	MASS PROPERTIES	INTERFACE VERIFICATION	EMC/EMI	ESD COMPATABILITY (GRD)	MAGNETICS	FUNCTIONAL	THERMAL VACUUM	THERMAL BALANCE	THERMAL CYCLE	HUMIDITY	RADIATION	BAKEOUT	BEAM TEST-EM SHOWERS	BEAM TEST-HADRONS	BEAM TEST - HEAVY IONS	COMMENTS
	C	VM2 CsI Det Elements (CDE)	12	Q	F	A			A			M	T	A	A	A	T	TQ		TQ		T					
	C	VM2 PreElect Modules (PEM)	1	Q	F	T	TQ	TQ	TQ		TQ	M	T				T	TQ		TQ			T				
	C	VM Electronics Prototype	1	Q	N												T										
ENGINEERING	C	EM CsI Det Elements (CDE)		Q	F/N							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	EM Composite Structure	1	Q	F	TQ						M											A				
	C	EM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A	A	T			TQ	M	A	A				
	S	**EM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T	T	T	TQ			M	A	A	T	T	T	
STRUCTURAL	S	**SM CAL Module**	1	Q	F	TQ	TQ	TQ	TQ			M											A				Structural Model
	S	**SFM CAL Module**	1	Q	F	TQ	TQ	TQ	TQ			M											A				Structural Flight Model
QUALIFICATION	C	QM CsI Det Elements (CDE)		Q	F							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	QM Composite Structure	1	Q	F	TQ						M											A				
	C	QM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A	A	T			TQ	M	A	A				
	S	**QM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T	T	T	TQ			M	A	A				
FLIGHT	C	FM CsI Det Elements (CDE)		F	F							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	FM Composite Structure		F	F	TA						M											QS				
	C	FM Front End Elect (AFEE)		F	N	QS	QS	QS	QS			M	T	QS	QS	QS	T			TQ	M	QS	QS				
	S	**FM CAL Module**	17	F	N		TA	TA	TA		QS	M	T	QS	QS	QS	T	TA			M	QS	QS				

LEVEL OF ASSEMBLY:
S = Subsystem
C = Component

SUPPLIER:
F = France
N = NRL

UNIT TYPE:
PR = ProtoFlight
F = Flight
S = Spare
Q = Qualification Unit

VERIFICATION METHOD:
T = Test
A = Analysis
M = Measurement
I = Inspection
TQ = Test, Qual. Level
QS = Qual by Similarity
TA = Test, Acceptance Level

3.2 Verification Methods

Verification methods for each of the performance requirements specified in the CAL Subsystem Level IV Specification, [LAT-SS-00210]. As specified, requirement verification may include analysis, inspection, or demonstration as well as environmental, functional, and performance testing.

3.2.1 Verification Method Definitions

a) Analysis – A verification method utilizing techniques and tools such as analytical assessments, simulations, models, or prior test data.

b) Inspection – A method of verifying physical characteristics without the use of special laboratory or test equipment, procedures, test support items, or services. Standard methods such as visual gauges, etc. are used to verify compliance with the requirements. Inspection also includes the review of design documentation, material lists, code, plans, etc.

c) Demonstration – A qualitative method of verification that evaluates the properties of the subject equipment by observation. It may be used with or without special test equipment or instrumentation to verify required characteristics such as functioning human engineering features, accessibility, transportability, or displayed data.

d) Test – A quantitative method of verification wherein performance requirements are verified by measurement during and after the controlled application of functional and environmental stimuli. These measurements usually require the use of special test equipment recorded data, procedures, laboratory equipment, or services.

4 GENERAL INFORMATION AND REQUIREMENTS

4.1 Test Facility Requirements

The facilities and test equipment used in verifying the Calorimeter components and system modules shall be capable of producing and maintaining the test conditions with the test specimen installed and operating or not operating as appropriate. In any major test, facility performance shall be verified prior to the test either by review of its performance during a test that occurred a short time earlier or by conducting a test with a substitute test item.

[Insert table here depicting Test Facility, Bldg., Specific Test, and perhaps contact information]

4.2 Contamination Control Requirements

Contamination control of flight and test hardware during the verification program shall be in accordance with the requirements of the Calorimeter, Tracker, and Data Acquisition Contamination Control Plan; [LAT-MD-00228-01]. Specific requirements for particulate or molecular contamination control shall be included in component/subsystem specifications and test plans and procedures.

4.3 Safety Requirements

System safety requirements that will be addressed in the Calorimeter System Safety Plan; [LAT-xx-00xxx] shall be included as appropriate during the verification program. Specific measures required to minimize the risks to equipment and personnel from hazards shall be included in the verification and test plans and procedures.

[Could not find callout for a Safety Plan in Calorimeter Drawing tree….may not be needed. Further discussion necessary.]

4.4 Waivers and Exceptions

A waiver of or exception to the requirements of this specification shall be granted only by direction or concurrence of the Calorimeter Project Manager or his authorized representative through the Configuration Management process.

4.5 Failure and Retest Requirements

When a failure (non-conformance or trend indicating that an out-of-spec condition will result) occurs, determination shall be made as to the feasibility and value of continuing the test to completion. If corrective action is taken, the test shall be repeated to the extent necessary to demonstrate that the test item's reliability and verify satisfactory performance.

If during a test sequence a test item is operated in excess of design parameters and becomes unsuitable for further testing, a spare may be substituted. However, if the substitution affects the significance of test results, the test during which the item was replaced and any previously completed tests that are affected shall be repeated to the extent necessary to demonstrate satisfactory performance.

Failures shall be recorded and tracked as a problem record through the Calorimeter Work Order Authorization database. A WOA shall be completed for each test procedure conducted on the Calorimeter Modules and subsequent problem records may be tracked to a given WOA. If a problem record is entered for a given anomoly, corrective action steps may be dispositioned to close out the problem record. WOA's shall not be closed out unless all problem records are dispostioned.

4.6 Test Readiness Review (TRR)

All Calorimeter module tests shall be preceded by a test readiness review wherein the readiness of the test article, facilities, test equipment, and procedures are verified. For minor tests (i.e. component tests), reviews may be conducted by the key test personnel as outlined by the given test procedure or directive. For major tests (i.e. CAL module tests), formal reviews shall be conducted and chaired by the Calorimeter Project Manager or his designated representative.

4.7 Release for Use Review (RFU)

Following the tests of the Calorimeter Modules, formal reviews shall be held wherein test data are reviewed to determine conformance with the test requirements prior to delivering any flight level deliverables. Test reports are required for all subsystem and system level qualification and flight level test programs.

Topics to be addressed at the review are as follows:

- Unit Revision Status
- Tests Performed and Summary Report
- Performance Review Summary
- Quality Review Summary
- Test Data Summary
- Problem / Failure Reports and Status
- Issues and Concerns
- Recommendations

The unit may be released for use after a successful RFU review with all open items closed. However, a unit may be released for use with open issues as long as there is a plan for closure and the open issues do not affect the higher-level integration.

The RFU review panel shall be comprised of representatives from Program Management, Systems Engineering, Performance Assurance, Subsystem Engineering, the IDT and other members of the collaboration as required. The panel will approve the release of the hardware for use on the LAT.

4.8 Test Sequence

In general, no specific test sequence is required, but the test program shall be arranged in a way to best disclose problems and failures associated with the characteristics of the hardware and the system requirements. The test sequence must satisfy the required verification tests for the given Calorimeter module. (Reference Table 2. Test Requirements Verification Matrix).

A detailed test sequence flow for the various Calorimeter Models are shown in Section x.x.

4.9 Documentation Requirements

The following procedures and reports are required to conduct the verification program and document the results.

4.9.1 Test Procedure and Supporting Analysis

All prototype and flight hardware shall be verified and tested using procedures approved by the Calorimeter Project. Test procedures shall be prepared to describe the activities required by this verification specification. Reference Section x.x for a listing of future documents that should be derived from this specification.

For each test activity, the procedure shall include the configuration of the test article, objectives, pre-test briefing, facilities, instrumentation, safety considerations, contamination control, test phases and profiles, functional operations and inspections, test software descriptions, personnel responsibilities, and the requirements for the reports. The interaction of the test and analysis shall be described and predictions provided.

Procedures shall also contain details such as test descriptions and purposes; identification of the test article; specific test equipment (including calibration information if applicable) and fixtures; facility control sequences; test parameters, levels and tolerances; identification of hazards and hazardous operations; contamination control provisions; quality control signoff points; data sheets; step-by-step (chronological) procedures; pass/fail criteria and/or expected results; and data collection, processing and reporting requirements.

All supporting analysis shall be referenced in the test procedure and a copy shall be attached to the test procedure at all times.

A WOA (Work Order Authorization) shall be completed referencing the name and LAT # of the procedure to be executed. This WOA form shall accompany the procedure at all times and serves as a means to track discrepancies that may be encountered while running the procedure.

Real-time modifications to the test procedures shall be captured by utilizing the red-line, black-line philosophy as follows:

- Red-Line – Real-time modifications to a test procedure for items which would be incorporated for re-run of test. Modifications require initial and date.
- Black-Line – Real-time modificatins for items which are one-time deviations to test. Modifications require initial and date.

4.9.2 Test Report

Test reports shall be prepared after the completion of test activities for the Calorimeter modules. For each test activity, the report shall contain, as a minimum, the following:

- Description of test
- Criteria for pass/fail (or expected results)
- Deviations that were taken from the approved test plan/procedures
- Test results
- Test data

5 TESTING

5.1 Summary of Required Tests and Demonstrations

The following tests, demonstrations, and supplemental analyses are required for Calorimeter Modules. Where items are indicated on a selective basis, the verification test matrix (Table 2 of this document) shows applicability.

- Performance Tests (CPT, LPT); (selective basis)
- Pressure Profile Verification Analysis
- Static Load Test; (selective basis)
- Mass Properties; (measurement)
- Minimum Modal Frequency Verification Test; (Sine Sweep)
- Sine Burst Vibration Strength Test
- Random Vibration Test
- Interface Verification Test
- EMC/EMI Tests; (selective basis)
- ESD Compatibility
- Magnetics
- Thermal Vacuum Test
- Thermal Cycle Test; (selective basis)
- Bakeout
- Burn In; (selective basis)
- Radiation Tests; (selective basis)???

The above tests and demonstrations, and appropriate analyses and inspections, shall be conducted to provide assurance that the Calorimeter components and subsystem modules meet specified performance, functional, environmental, science, and design requirements.

5.2 Calorimeter Test Sequence

The Calorimeter shall be comprised of sixteen modules (Reference Figure 1, Section 2). These modules are considered flight models and shall be delivered and integrated to the LAT instrument. However, prior to production of the flight modules, three other modules shall be built and tested. These are the Engineering, the Structural, and Qualification CAL Module Models and shall be addressed in the following sections.

5.2.1 Engineering Model CAL Module

One Engineering Model (EM) CAL Module shall be built and tested at the qualification level. Subsequent CAL Models shall leverage manufacturing techniques and performance requirements from the engineering model. The EM Model shall be as close a representation of the Flight CAL modules as possible. The differences from the flight model are as follows:

- Dual PIN photodiodes shall be modified for flight.
- Optical epoxy used to bond PIN photodiodes to Crystals likely to change.
- EM CDE's manufactured in the USA.
- Carbon Composite Structure will use an improved curing process for flight.
- Anything else????

The flow of the Engineering Model CAL Module is shown in Figure 2 below:

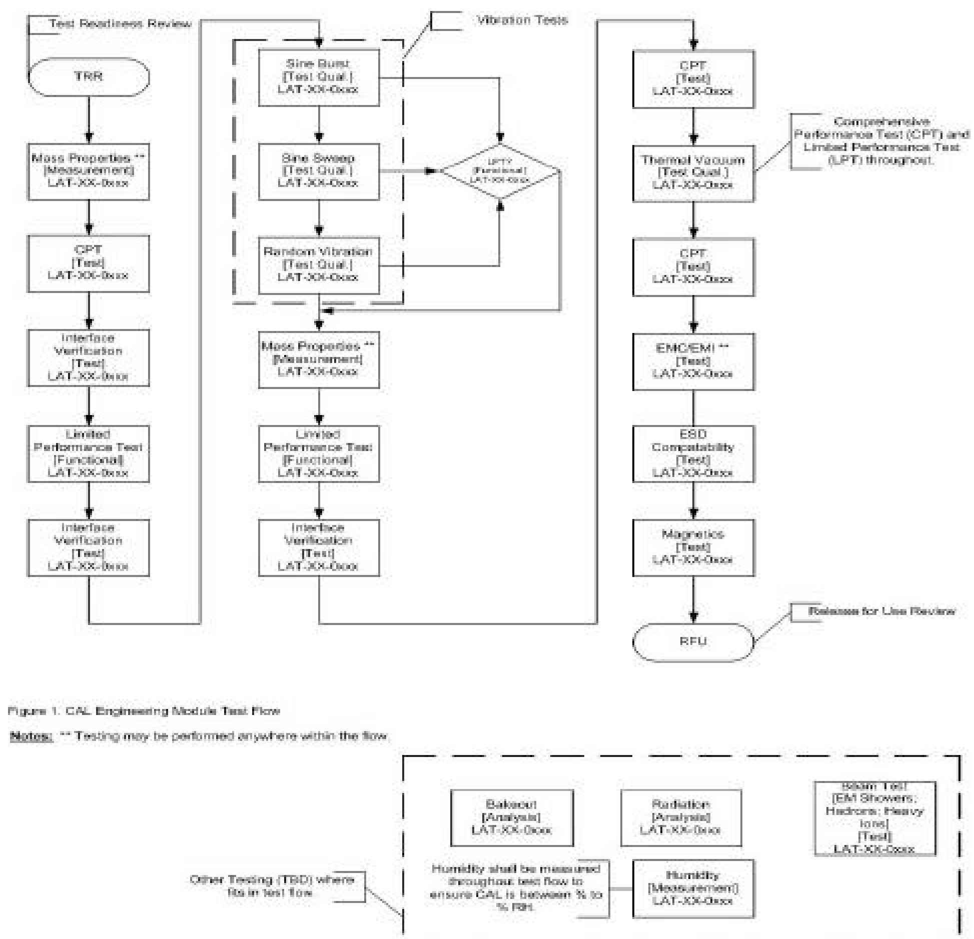


Figure 2: CAL Engineering Module Test Flow

5.2.2 Structural Model CAL Module

One Structural Model (SM) CAL module shall be built and tested at the qualification level. The composite structure is being fabricated by a French vendor and this model shall verify their production processes are satisfactory and repeatable. (Please feel free to embelish upon sections 5.2.2.and 5.2.3)

5.2.3 Structural Flight Model CAL Module

One Structural Flight Model (SFM) CAL module shall be built and tested a the qualification level. The reason for a structural flight model is to verify process control and manufacturability has not changed. The structural flight model shall be produced using an autoclave. Once this model is tested and proven reliable, subsequent structures shall be mass produced.

The flow of the Structural / Flight Structural Model CAL Module is shown in Figure 3 below:

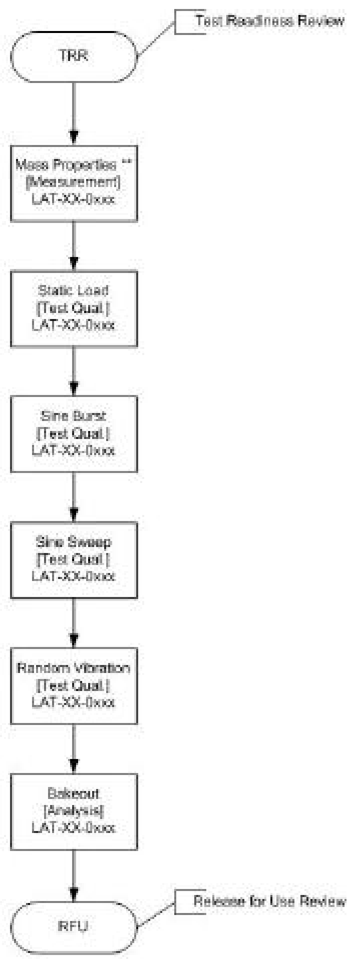


Figure 4. CAL Structural Model / Structural Flight Model Test Flow

Notes: ** Testing may be performed anywhere within the flow.

Figure 3: CAL Structural / Structural Flight Module Test Flow

5.2.4 Qualification Model CAL Module

One Qualification Model (QM) CAL Module shall be built and tested at the qualification level. Subsequent Flight CAL Models shall leverage manufacturing techniques and performance requirements from the qualification model. The qualification model shall be identical in components and manufacturing processes to the flight units.

The flow of the Qualification Model CAL Module is shown in Figure 4 below:

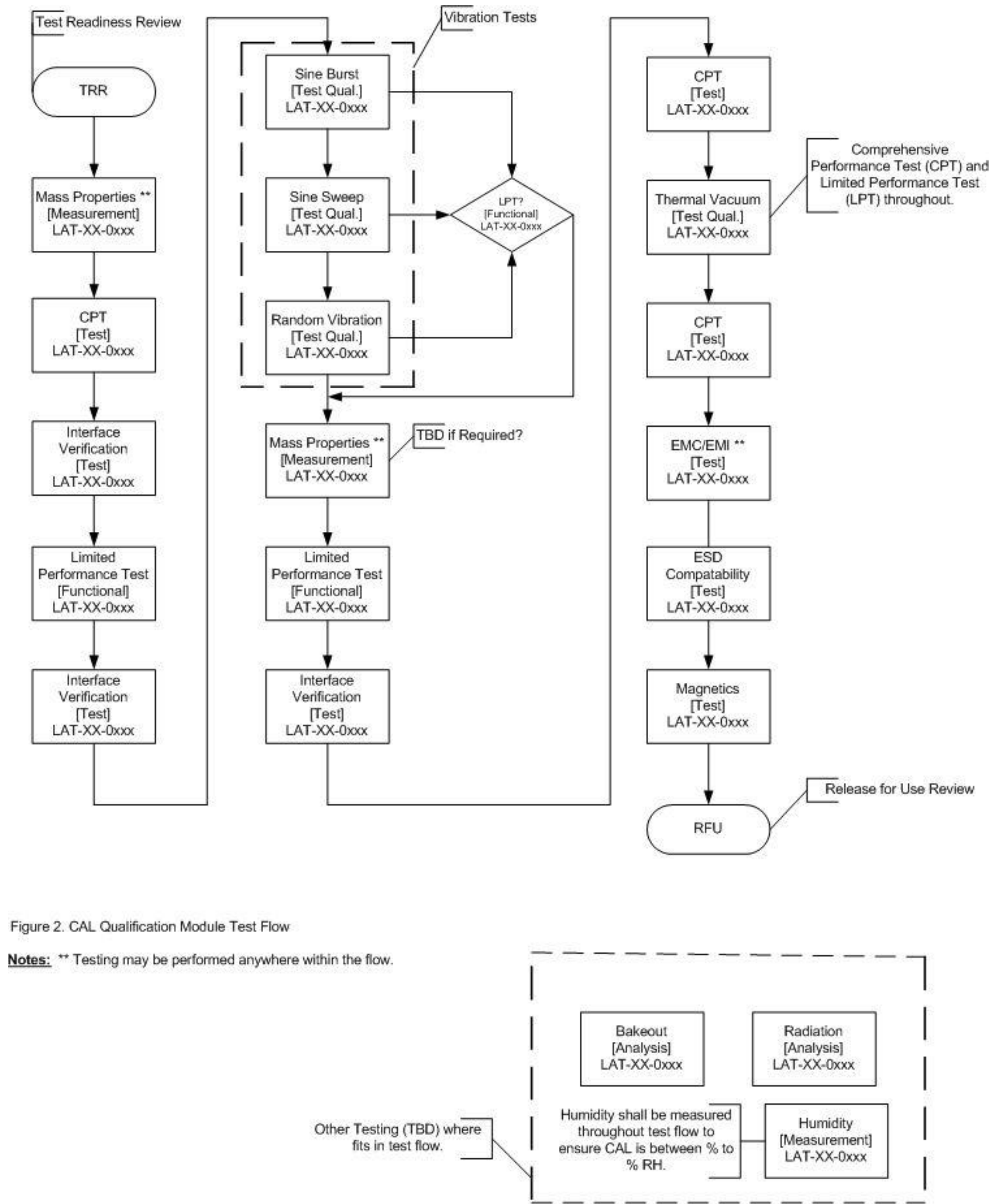


Figure 4: CAL Qualification Module Test Flow

5.2.5 Flight Model CAL Module

Seventeen Flight Model (FM) CAL Modules shall be built and tested at the acceptance level or deemed qualified by similarity. Sixteen of these modules, after passing the environmental test phase shall be delivered to the LAT instrument for integration. One module shall be reserved as a flight spare in the event a module shall become unusable.

The flow of the Flight Model CAL Module is shown in Figure 5 below:

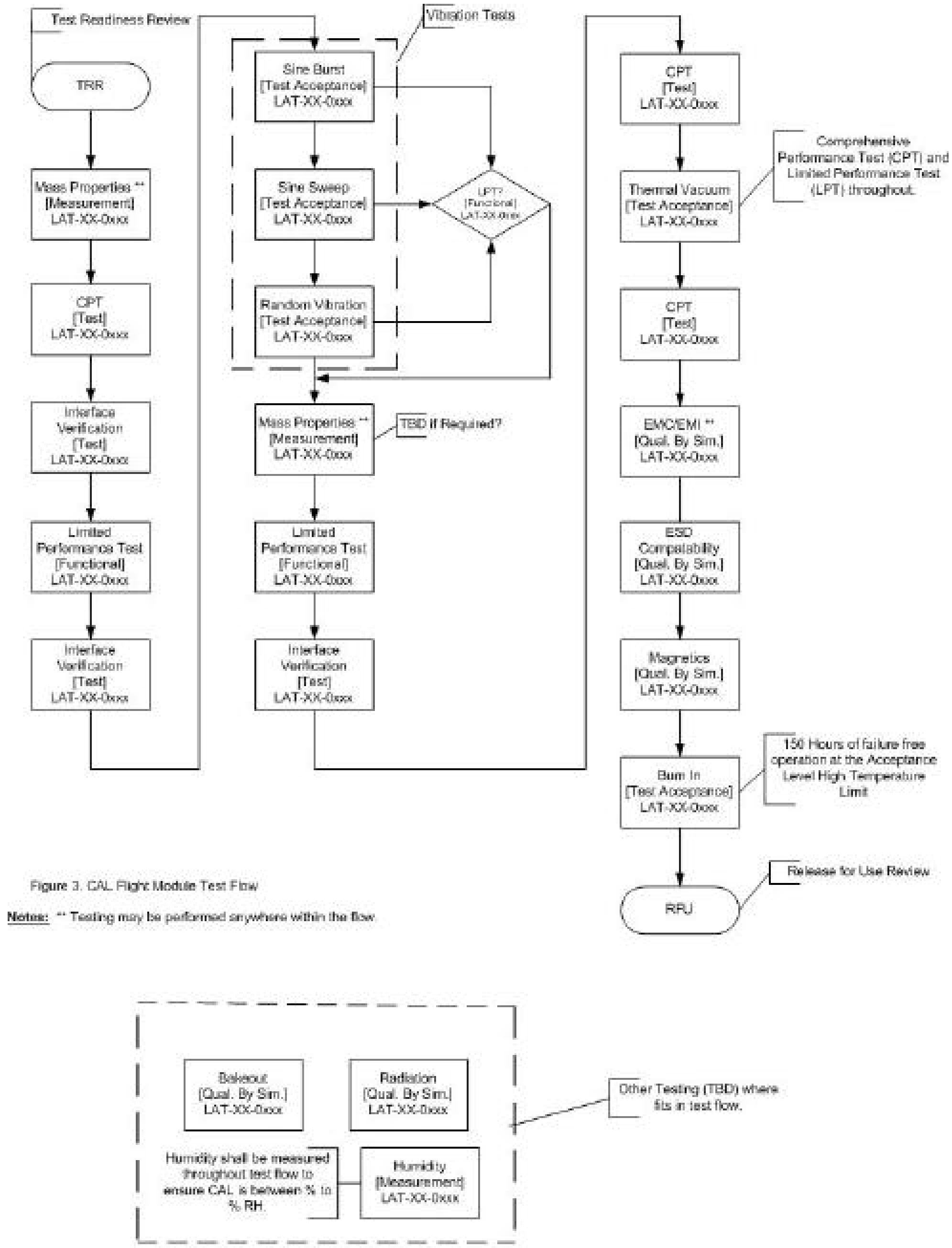


Figure 5: CAL Flight Module Test Flow

5.3 Science Verification and Calibration Tests

5.3.1 Comprehensive Performance Tests (CPT)

Comprehensive performance tests shall be executed prior to and after each environmental test of each CAL Module. Data taken from each test is then compared to see if any changes to the test article has changes as a result of the environmental test. During Thermal Vacuum testing, CPTs shall be run under vacuum at ambient, and High/Low temperatures during first and last thermal cycles. The operating performance of the CAL Module shall be verified over environmental ranges as well as specific CAL operational ranges. Primary and redundant circuitry shall be functionally verified as well during the CPT.

5.3.2 Limited Performance Tests (LPT)

A Functional test of the CAL Modules shall be performed after the interface verification test to ensure the unit powers up correctly, and all circuit connections are in proper working order. This test shall be completed before each environmental test and during transitions during thermal vacuum testing to check for intermittent failures.

5.4 Mechanical Tests

The following sections shall address the various mechanical verification methods (environmental tests, measurements, analysis, or inspection) that CAL Modules may be subject to.

5.4.1 Pressure Profile Verification Analysis

LAT components and assemblies shall be capable of withstanding the time rate of change of pressure in the launch vehicle fairing, as shown in Figure 6, below. In accordance with GEVS section 2.4.6, qualification by analysis must demonstrate a positive margin with respect to the maximum profile shown of 100%. Acceptance verification is not required.

Source of requirement: MSS 3.2.5.2

Data sources:

MDC 00H0016, "Delta II Payload Planners Guide (PPG)", October 2000, Section 4.2.1, Figure 4-6

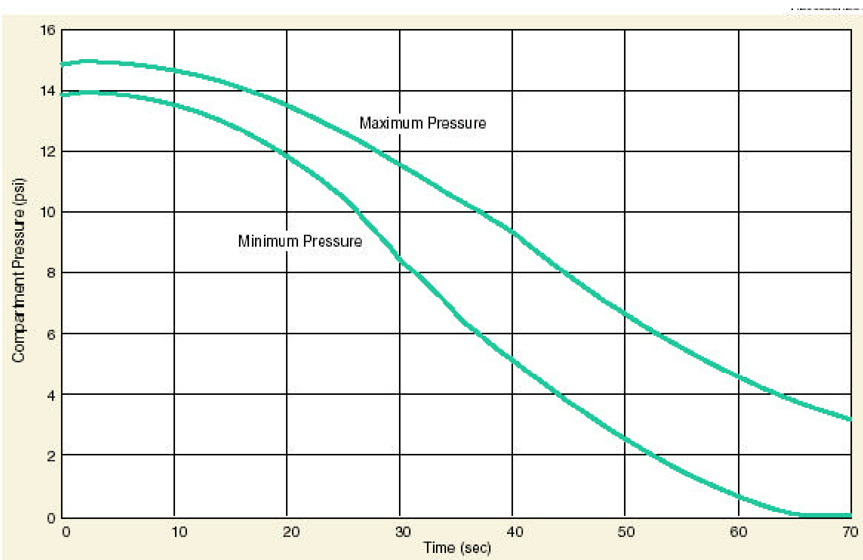


Figure 4-6. Delta II Payload Fairing Compartment Absolute Pressure Envelope

Figure 6: Pressure Rate-of-Change During Launch Profile

5.4.2 Static Load Test

CAL components and subsystem modules shall be designed after exposure to the static-equivalent accelerations at their center-of-mass as shown in Table 3 below.

For testing purposes, peak accelerations need only be applied one axis at at time.

Data source:

"LAT Environmental Specification"; [LAT-SS-00788] Section 8.1

Table 3: CAL Static-Equivalent Accelerations

CAL	Design		Accept	Qual	Unit
Launch Event	Lift-Off/ Transonic	MECO			
Lateral	2.14	0.2	6	6.8	g
Axial	4.43	6.8	6.8	8.5	g
Rot X/Y	19.8	0	0	0	rad/sec^2
Rot Z	20.2	0	0	0	rad/sec^2
Source	(2)	(3)	(5)	(5)	
Scale Factor				1.25	

5.4.3 Mass Properties

Measurement of the weight, center of gravity, and moment of inertia of each CAL component and subystem module shall be made to show compliance with the Requirements Verification Matrix (Table 2, Req't # 5.12, Calorimeter Mass) and provide accurate data for the LAT mass properties control program.

5.4.4 Vibration Testing

5.4.4.1 MINIMUM MODAL FREQUENCY VERIFICATION TEST

CAL modules shall be subjected to a low level sine sweep vibration test to verify its minimum modal frequency in each of three mutually perpendicular axis, one of which is normal to the mounting surface. This test should be performed in conjunction with the sine burst vibration test of Section 5.4.4.2.

5.4.4.2 SINE BURST VIBRATION STRENGTH TEST

Strength Verification of CAL Modules shall be demonstrated by subjecting the test article to (TBD) times limit loads based on the quasi-static and dynamic loads during flight on the Delta II launch vehicle. [Assumptions made from review of LAT Performance Specification that levels represent those outlined in the Payload Planners Guide for the Delta II launch vehicle.] This shall be performed on CAL components and subsystem modules by using a low frequency sine burst technique, which is applied during during the same test setup as that required for the random vibration test of section 5.4.4.3.

Test frequencies shall be selected that are low enough to assure rigid body motion of the test article and still be compatible with the low frequency limitations of the test shaker system (if these conditions cannot be met, alternate means of testing, such as using a centrifuge, shall be considered). The number of sinusoidal dwells, or reversals, made at specific levels during the test shall be 10 plus or minus 5 cycles. The test shall be performed in each of the three orthogonal axes.

Sine Qualification and Acceptance Levels are shown in Tables 4&5 below

Data Sources: LAT-TD-00788, LAT Environmental Test Parameters.

Table 4: Sine Qualification Test Levels

Sine Qualification Test Levels			
Axis	**Frequency (Hz)**	**Test Levels**	**Sweep Rate**
Thrust	5 to 7.4 / 7.4 to 50	1.27 cm (0.5 in.) double amplitude 1.4 g (zero to peak)	2 octaves/min
Lateral	5 to 6.2 /6.2 to 50	1.27 cm (0.5in.) double amplitude 1.0 g (zero to peak)	2 octaves/min

Table 5: Sine Acceptance Test Levels

Sine Acceptance Test Levels			
Axis	**Frequency (Hz)**	**Test Levels**	**Sweep Rate**
Thrust	5 to 6.2 / 6.2 to 50	1.27 cm (0.5 in.) double amplitude 1.0 g (zero to peak)	4 octaves/min
Lateral	5 to 50	0.7 g (zero to peak)	4 octaves/min

5.4.4.3 RANDOM VIBRATION TES T

CAL components and subsystem modules shall be subjected to a random vibration test at the qualification level. For the production Flight Modules, the random vibration test shall be at the acceptance levels.

Vibration is comprised of a random-signal spectrum of frequencies anywhere in the range from 20 Hz to 2,000 Hz. The required test levels in Table 6 are based on the Delta II launch vehicle acoustic levels from engine coupling to spacecraft structure, and aerodynamic noise levels. These levels shall be applied in each of three orthogonal axes of the component, one axes being perpendicular to the mounting surface. During the test, the test article shall be operated in a mode representative of that during launch [I assume the instrument will be powered off for launch…] Gaussian random vibration shall be applied for one minute per axis. [TBD].

Random Vibration Qualification and Acceptance Levels are shown in Table 6 and outlined in Figure 7 below.

Data Sources: LA T-TD-00788, LAT Environmental Test Parameters.

Table 6: Calorimeter Module Random Vibration Acceptance / Qualification Levels

Frequency (Hz)	ASD Level (G^2/Hz)	
	Acceptance	Qualification
20	0.005	0.010
50	0.021	0.041
800	0.021	0.041
2000	0.005	0.010
Overall	5.8 Grms	7.4 Grms

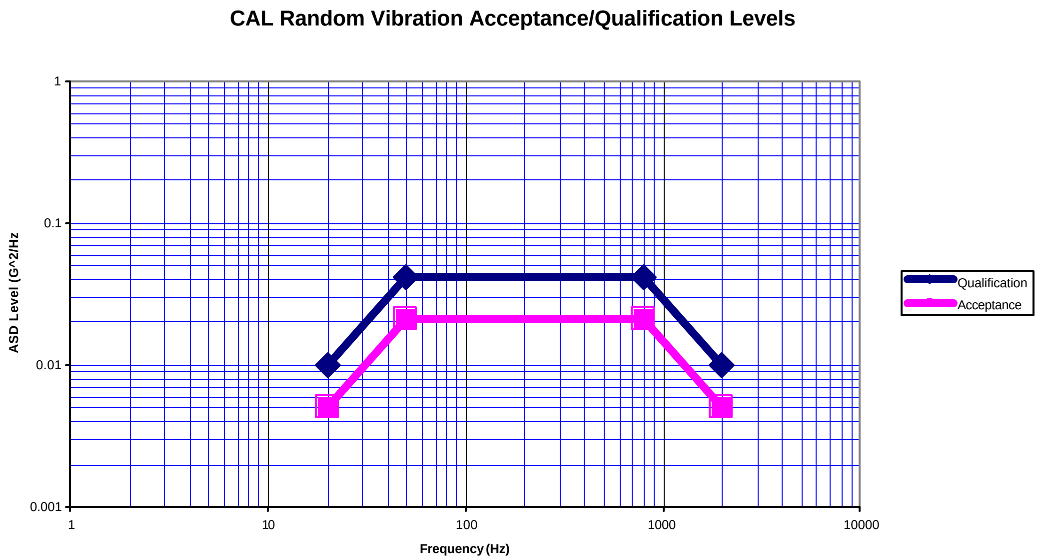


Figure 7: CAL Module Random Vibration Acceleration Spectral Density

5.5 Electrical Tests

The following sections shall address the various electrical verification methods (environmental tests, measurements, analysis, or inspection) that CAL Modules may be subject to.

5.5.1 Interface Verification

Interface verification tests (safe-to-mate) are performed prior to integration to flight hardware. The test serves to verify the integrity of the electrical interfaces (EGSE and Flight) and prevent damage to flight hardware as a result of equipment move, and mating/demating of connectors. The flowing tests may be performed as part of interface verification:

- Isolation
- Continuity
- Grounding
- Insulation Resistance (Hi-Pot)
- Power Distribution
- Command Distribution
- Signal Distribution

5.5.2 EMC/EMI

The general requirements for electromagnetic compatibility are as follows:

a) The Calorimeter Module electronics shall not generate electromagnetic interference that could adversely affect its own subsystems and components, other spacecraft level payloads, or the safety and operation of the launch vehicle (Delta II) and launch site.

b) The Calorimeter Module electronics shall not be susceptible to emissions that could adversely affect their safety and performance. This applies whether the emissions are self generated or emanate from other sources.

The CAL Module electronics shall be designed to function properly while operating in an electro magnetic field environment as defined by the following Emission and Susceptibility requirements as show in Table 7 below. The tests are performed to fixed levels which are intended to envelope those that may be expected during a typical mission and allow for some degradation of the hardware during the mission. The levels should be tailored to meet mission specific requirements, such as, the enveloping of launch vehicle and launch site environments.

Radiated Emissions and Susceptibility testing will be performed on each component at the levels as stated in the GLAST Electronmagnetic Interference (EMI) Requirements Document; [433-RQMT-0005], MIL-STD-461E; Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment (20 August 1999) and those taken from the GEVS-SE; General Environmental Verification Specification For STS & ELV Payloads, Subsystems, and Components.

Table 7 below depicts the Calorimeter applicable Emission and Susceptibility Requirements for Space Systems including Launch Vehicles as outlined from MIL-STD-461E.

Table 7: Emission and Susceptibility Requirements

Requirement	Description
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CECM	Conducted Emissions, Common Mode
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS114 (TBC)	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115 (TBC)	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz
RE101*	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz

Requirement	Description
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RS101*	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz
RS103	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz
* MIL-STD-461E does not address these as applicable for spacecraft platforms.	

5.5.2.1 CONDUCTED EMISSIONS, POWER LEADS, 10 KHZ TO 10 MHZ, (CE102)

The requirement is applicable from 10 kHz to 10 MHz for all power leads, including returns, that obtain power from other sources not part of the Calorimeter Module. Conducted emissions on power leads shall not exceed the applicable values shown on Figure 8.

The test procedure for performing Conducted Emission testing may be found in Section (5.5.3) of MIL-STD-461E.

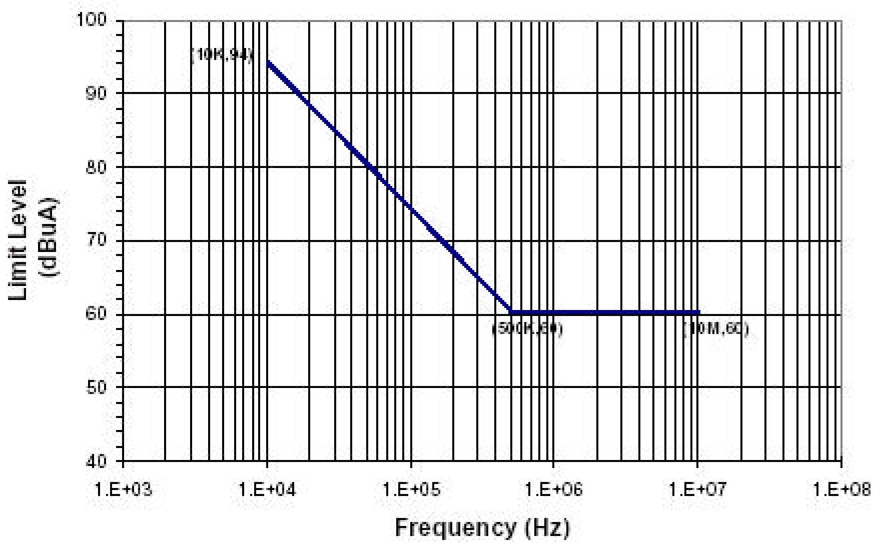


Figure 8: Conducted Emissions, Power Leads, 10 KHz to 10 MHz (CE102)

5.5.2.2 CONDUCTED EMISSIONS, COMMON MODE (CECM)

Data Sources: LAT Environmental Specification; [LAT-SS-00778-01-D7]

Electromagnetic Interference (EMI) Requirements Document; [433-RQMT-0005]

Calorimeter Modules shall limit prime power common mode conducted emissions to levels less than the limits specified in Figure 9, and 100mV peak-to-peak (TBR) in the time domain.

Calorimeter Modules shall limit repetitive spikes to less than the limits specified in Figure 8 and Figure 9.

Hard copies of this document are for REFERENCE ONLY and should not be considered the latest revision.

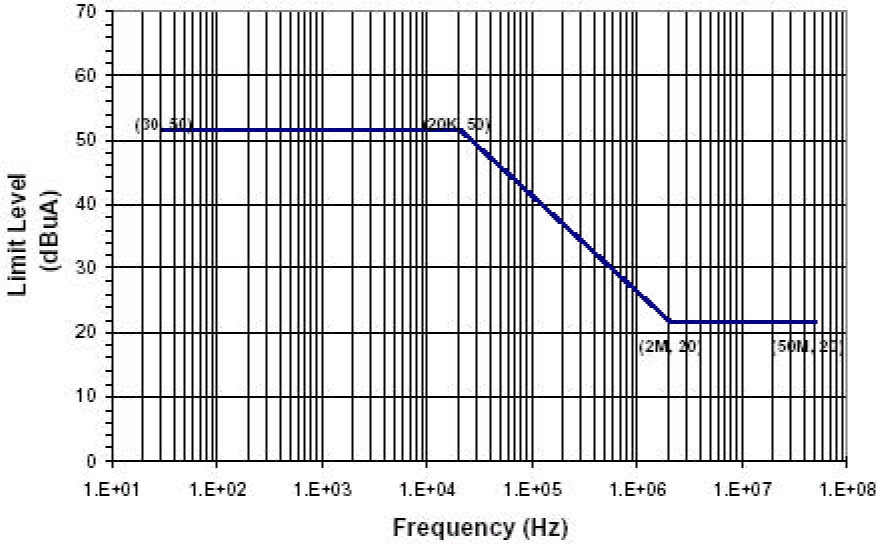


Figure 9: Common Mode Conducted Emissions Limits (CECM)

5.5.2.3 CONDUCTED SUSCEPTIBILITY, POWER LEADS, 30 HZ TO 150 KHZ, (CS101)

Calorimeter Modules shall perform when subjected to conducted sinewave and pulse modulated noise injected on the primary power input as specified in Figure 10.

Note: The definition for peform requirement is defined in Section 1.4.2 of this document.

This requirement is applicable to equipment and subsystem AC and DC input power leads, not including returns. If the test article is DC operated, this requirement is applicable over the frequency range of 30 Hz to 150 kHz. If the test article is AC operated, this requirement is applicable starting from the second harmonic of the test article's power frequency and extending to 150 kHz.

The test procedure for performing Conducted Susceptibility testing may be found in Section (5.7.3) of MIL-STD-461E.

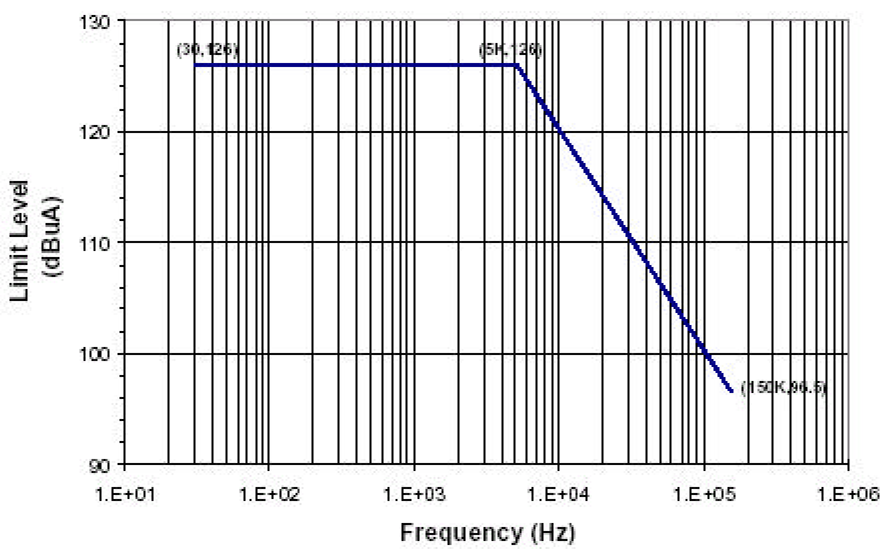


Figure 10: Instrument Conducted Susceptibility Limit (CS101)

5.5.2.4 CONDUCTED SUSCEPTIBILITY, BULK CABLE INJECTION, 10 KHZ TO 200MHZ, (CS114)

Note: This requirement was not addressed per LAT Environmental Specification; [LAT-SS-00778]. However, MIL-STD-461E does specify this particular requirement is applicable to spacecraft applications and therefore is addressed below, and should be considered for CAL Module EMI/EMC testing.

This requirement is applicable to all interconnect cables, including power cables. The test article shall demonstrate the ability to withstand RF signals coupled onto associated calorimeter cabling when subjected to an injection probe drive level which has been pre-calibrated to the appropriate limit curve in Figure 12 (CS114) and modulated as required. The appropriate limit curve shall be Curve #3 (Figure 11) for Space specific applications. Requirements are also met if the test article is not susceptible at forward power levels sensed by the coupler that are below those determined during calibration provided that the actual current induced in the cable under test is 6 dB ≥ the calibration limit.

The test procedure for performing Conducted Susceptibility testing (10 kHz to 200 MHz) may be found in Section (5.12.3) of MIL-STD-461E.

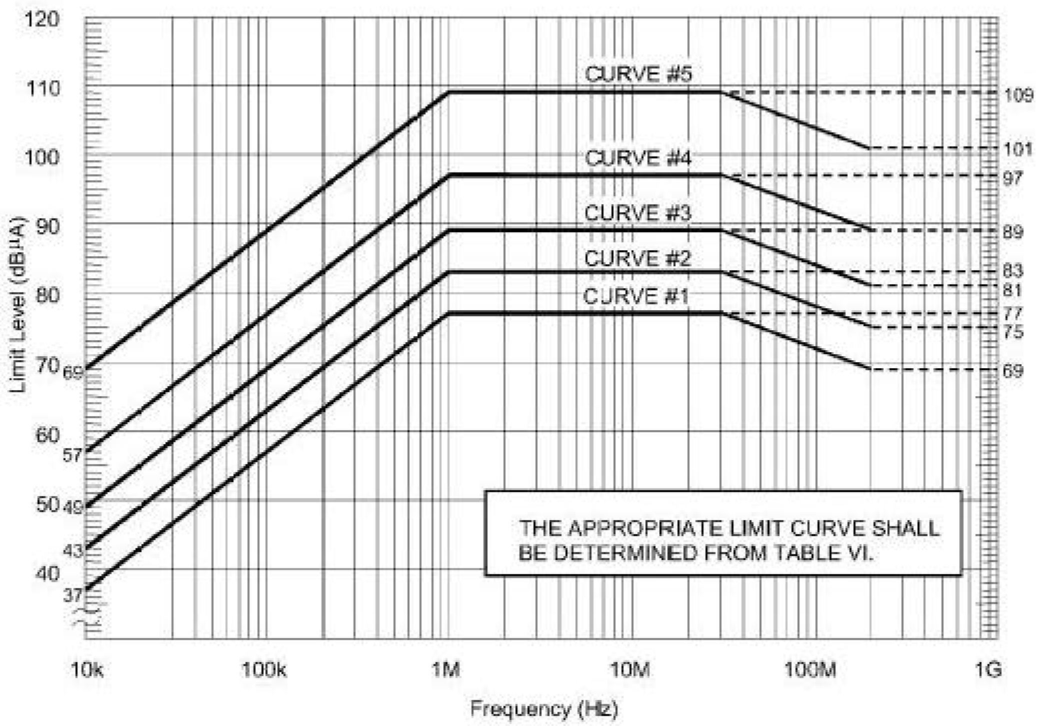


Figure 11: Calibration limit for all applications; Curve #3 for Space Applications (CS114)

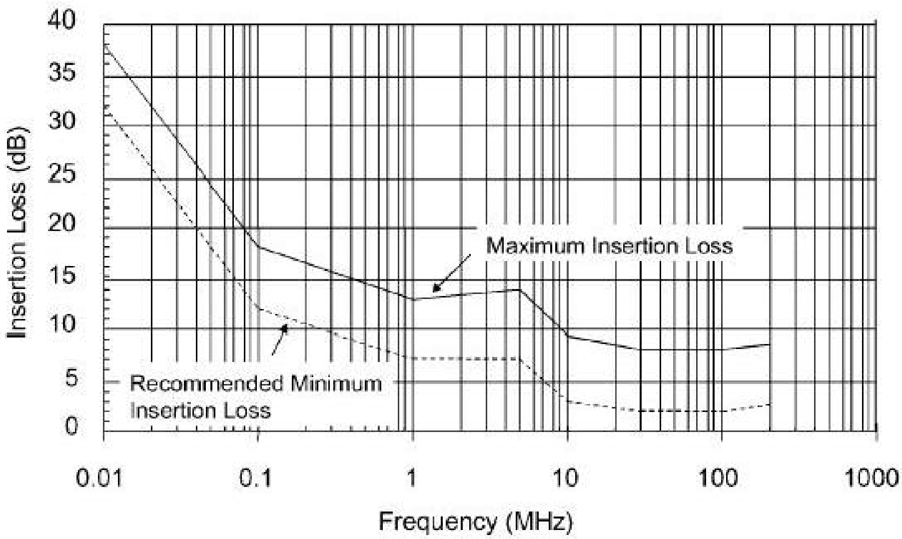


Figure 12: Maximum insertion loss for injection probes (CS114)

5.5.2.5 CONDUCTED SUSCEPTIBILITY, BULK CABLE INJECTION, IMPULSE EXCITATION, (CS115)

Note: This requirement was not addressed per LAT Environmental Specification; [LAT-SS-00778]. However, MIL-STD-461E does specify this particular requirement is applicable to spacecraft applications and therefore is addressed below, and should be considered for CAL Module EMI/EMC testing.

This requirement is applicable to all aircraft, space, and ground system interconnecting cables, including power cables. The Calorimeter module shall not exhibit any malfunction, degradation of performance, or deviations from unit specification, when subjected to a pre-calibrated signal having rise and fall times, pulse width, and amplitude as specified in Figure 13 at a 30 Hz rate for a one minute time interval.

The test procedure for performing Conducted Susceptibility testing (Impulse Excitation) may be found in Section (5.13.3) of MIL-STD-461E.

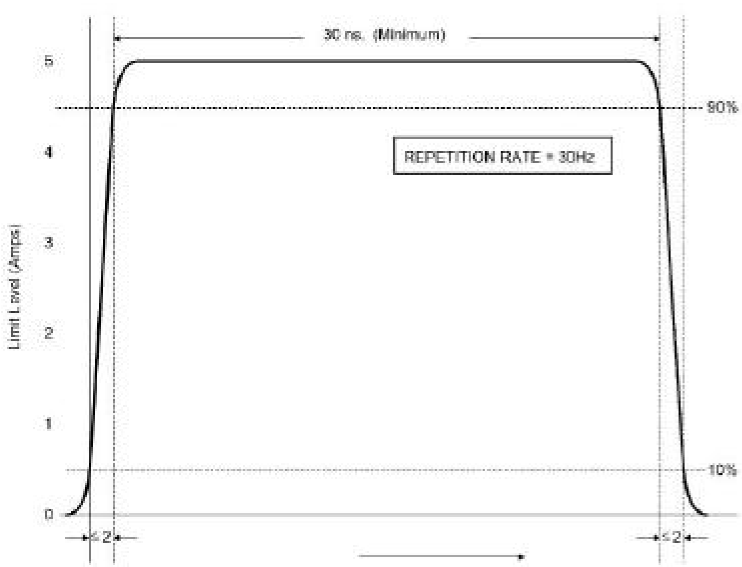


Figure 13: Signal Characteristics for all applications (CS115)

5.5.2.6 CONDUCTED SUSCEPTIBILITY, DAMPED SINSUSOIDAL TRANSIENTS, CABLES AND POWER LEADS, 10 KHZ TO 100 MHZ, (CS116)

Calorimeter Modules shall operate when subjected in the powered state to both positive and negative polarity transients injected on the primary power input (line-to-line) as shown in Figures 14 and 15.

Calorimeter Modules shall operate after being subjected in the unpowered state to both positive and negative polarity transients injected on the primary power input (line-to-line) as shown in Figures 14 and 15.

Calorimeter Modules shall survive when subjected to both positive and negative polarity fuse blow/fault transients injected on the primary power input leads (28V line-to-chassis and return-to-chassis) as shown in Figure 16 (TBS). This requirement applies with the unit operating (powered) and nonoperating (unpowered). Testing, to verify compliance, shall be restricted to nonflight hardware. Therefore, this requirement shall be applied only to the EM and QM CAL Modules.

Calorimeter Modules shall perform when subjected to transient noise injected on the primary power input as shown in Figure 17 and 18.

Note: Definitions for operate, survive, and peform requirements are defined in Section 1.4.2 of this document.

This requirement is applicable to all interconnecting cables, including power cables, and individual high side power leads. Power returns and neutrals need not be tested individually. The Calorimeter module shall not exhibit any malfunction, degradation of performance, or deviations from unit specification, when subjected to a signal having the waveform shown in Figure 15 and having a maximum current as specified in Figure 14. The limit is applicable across the entire specified frequency range. As a minimum, compliance shall be demonstrated at the following frequencies: 0.01, 0.1, 1, 10, 30, and 100 MHz. If there are other frequencies known to be critical to the equipment installation, such as platform resonances, compliance shall also be demonstrated at those frequencies. The test signal repetition rate shall be no greater than one pulse per second, and no less than one pulse every two seconds. The pulses shall be applied for a period of five minutes.

The test procedure for performing Conducted Susceptibility testing (Damped Sinusoidal Transients) may be found in Section (5.14.3) of MIL-STD-461E.

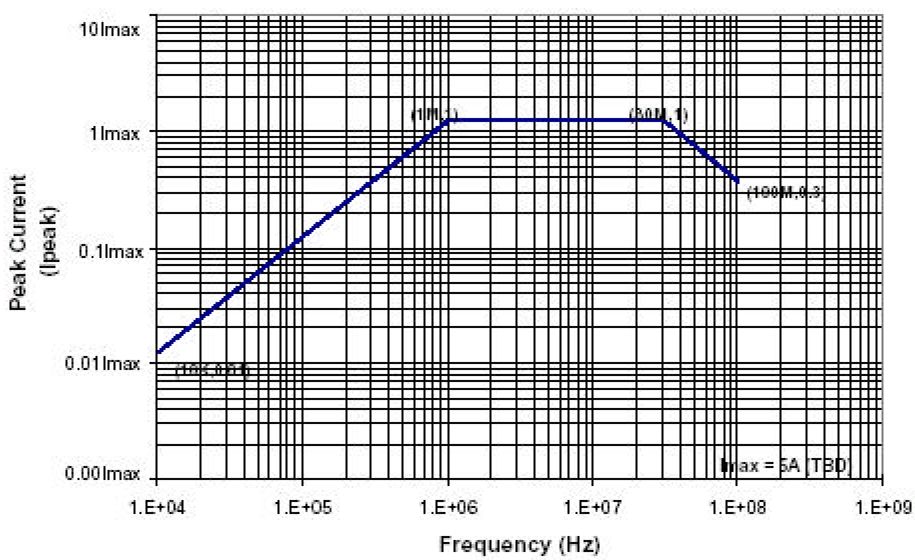
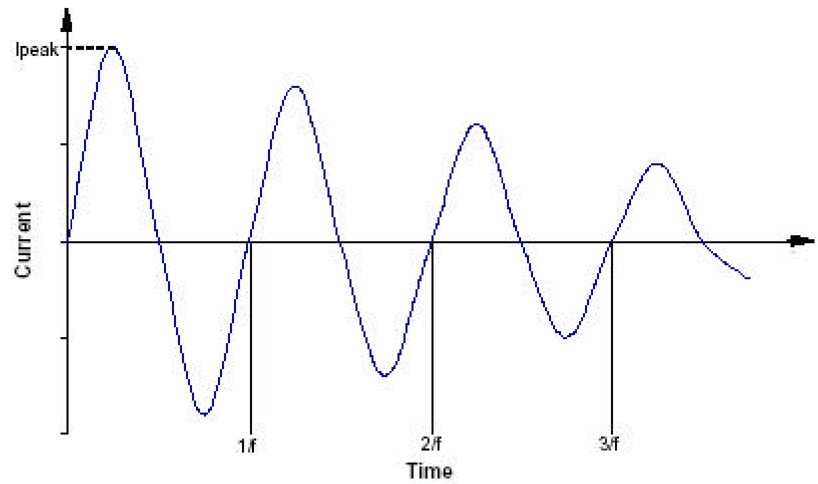


Figure 14: Instrument Conducted Transient Susceptibility Limit (CS116-Operate)



NOTES: 1. Normalized waveform: $e^{-(\pi ft)/Q}\sin(2\pi ft)$

Where:
f = Frequency (Hz)
t = Time (sec)
Q = Damping factor, 15 ± 5

2. Damping factor (Q) shall be determined as follows:

$$Q = \frac{\pi(N-1)}{\ln(I_P/I_N)}$$

Where:

Q = Damping factor
N = Cycle number (i.e. N = 2, 3, 4, 5, ...)
I_P = Peak current at 1st cycle
I_N = Peak current at cycle closest to 50% decay
ln = Natural log

3. I_P as specified in Figure 14

Figure 15: Instrument Conducted Susceptibility, Damped Sinusoidal Transient Limit (CS116 – Operate)

[INSERT FIGURE 16 HERE]

Figure 16: Instrument Conducted Susceptibility, Fuse Blow/Fault Transient Susceptibility Limit (CS116 – Survive) (TBS)

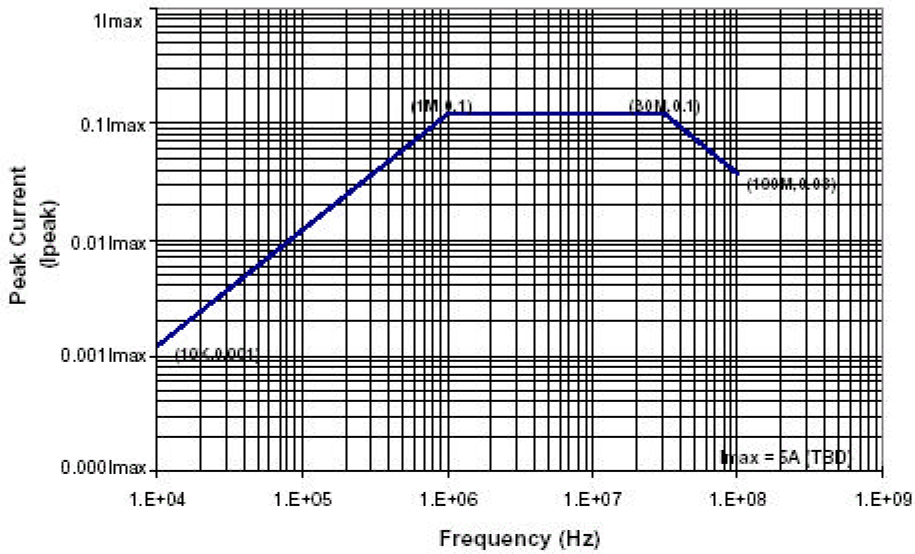
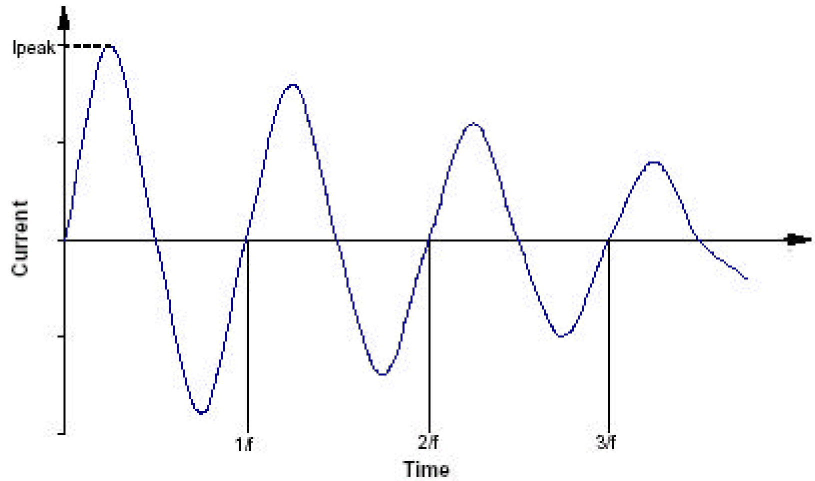


Figure 17: Instrument Conducted Susceptibility Limit (CS116 – Perform)



NOTES: 1. Normalized waveform: $e^{-(\pi ft)/Q}\sin(2\pi ft)$

Where:
f = Frequency (Hz)
t = Time (sec)
Q = Damping factor, 15 ± 5

3. Damping factor (Q) shall be determined as follows:

$$Q = \frac{\pi(N-1)}{\ln(I_P/I_N)}$$

Where:

Q = Damping factor
N = Cycle number (i.e. N = 2, 3, 4, 5, ...)
I_P = Peak current at 1st cycle
I_N = Peak current at cycle closest to 50% decay
ln = Natural log

3. I_P as specified in Figure 17

Figure 18: Instrument Conducted Susceptibility, Damped Sinusoidal Transient Limit (CS116 – Perform)

5.5.2.7 RADIATED EMISSIONS, MAGNETIC FIELD, 30 HZ TO 100 KHZ, (RE101)

Data Sources: LAT Environmental Specification; [LAT-SS-00778-01-D7]

Electromagnetic Interference (EMI) Requirements Document; [433-RQMT-0005]

Note: MIL-STD-461E does not specify requirement RE101 applicable for spacecraft platforms, but to be consistent with the 433-RQMT-0005, it has been included below.

Calorimeter Modules shall limit unintentional magnetic filed emissions to less than the limits specified in Figure 19. when measured at a distance of 1 meter from the instrument enclosure.

This requirement is applicable to radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces. The requirement does not apply to radiation from antennas.

The test procedure for performing Radiated Emission testing (Electric Field) may be found in Section (5.15.3) of MIL-STD-461E.

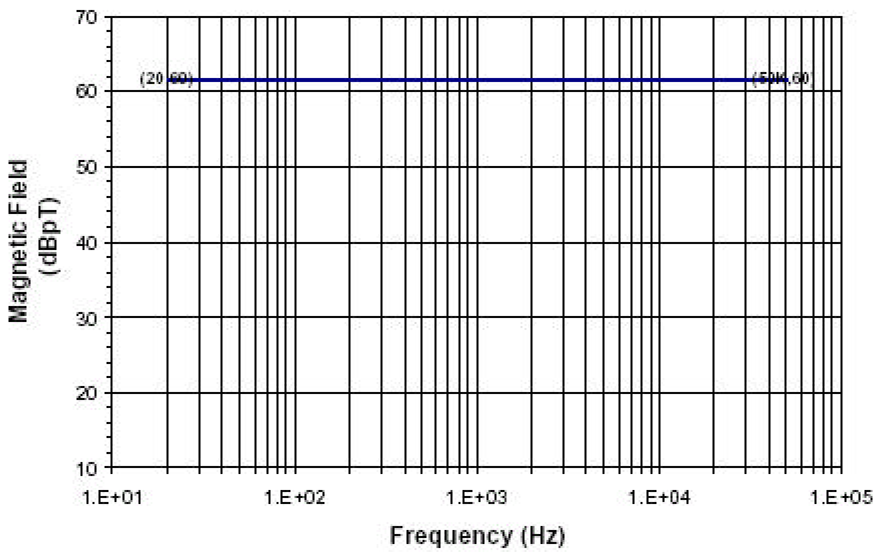


Figure 19: Instrument Radiated Magnetic Field Emissions Limit (RE101)

5.5.2.8 RADIATED EMISSIONS, ELECTRIC FIELD, 10 KHZ TO 18 GHZ, (RE102)

Calorimeter Modules shall limit unintentional electric field emissions to levels less than the limits specified in Figure 20. Instruments consisting of more than one stand-alone component (Calorimeter Modules) shall meet the levels of Figure 20 for each component. Measurement bandwidths above 1 GHz may be modified, if necessary, to achieve sufficient EMI receiver sensitivity.

This requirement is applicable for radiated emissions from equipment and subsystem enclosures, all interconnecting cables, and antennas designed to be permantly mounted to the test article (receivers and transmitters in standby mode). The requirement does not apply to the transmitter fundamental frequencies. The requirement is applicable as for Space applications over the frequency range of 10 kHz to 18 GHz. However, testing is required up to 1 GHz or 10 times the highest intentially generated frequency within the test article, whichever is greater. Measurements beyond 18 GHz are not required.

Electric field emissions shall not be readiated in excess of those shown in Figure 15 above 30 MHz, the limits shall be met for both horizontally and veritically polarized fields.

The test procedure for performing Radiated Emission testing (Electric Field) may be found in Section (5.16.3) of MIL-STD-461E.

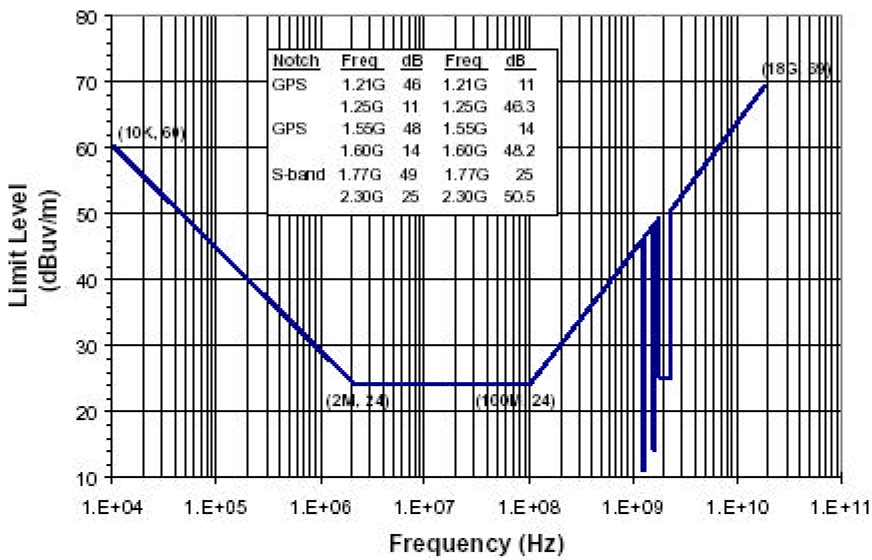


Figure 20: Instrument Radiated Electric Field Emissions Limits (RE102)

5.5.2.9 RADIATED SUSCEPTIBILITY, MAGNETIC FIELDS (RS101, STATIC)

The Calorimeter Modules shall perform when subjected to the radiated maganetic field requirement of Figure 21 and the magnetic field requirement of Figure 22 (TBS). Figure 22 shows the estimate of the worst-case magnetic fields at various locations on the Spacecraft produced by the magnetic torque rods.

Note: The definition for peform requirement is defined in Section 1.4.2 of this document.

[MIL-STD-461E does not specify RS101 as an applicable requirement for spacecraft platforms, but to be consistent with 433-RQMT-0005], it has been included.]

The test procedure for performing Radiated Susceptibility testing (Magnetic Fields) may be found in Section (5.15.3) of MIL-STD-461E.

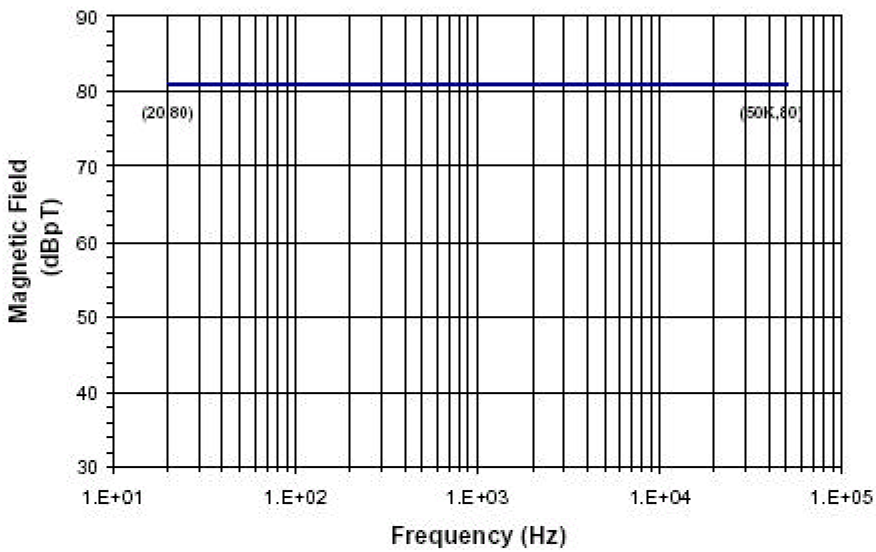


Figure 21: Instrument Magnetic Field Radiated Susceptibility Performance Limit

[FIGURE 22 TO BE INSERTED HERE]

Figure 22: Observatory Torquer Rod Magnetic Fields (TBS)

5.5.2.10 RADIATED SUSCEPTIBILITY, ELECTRIC FIELD, 2 MHZ TO 40 GHZ, (RS103)

The Calorimeter Modules shall survive exposure to the radiated susceptibility environments specified in Figure 23.

The Calorimeter Modules shall perform when subjected to the radiated susceptibility environment specified in Figure 24.

Note: Definitions for survive, peform requirements are defined in Section 1.4.2 of this document.

The applicability of the above susceptibility criteria verses the applied environmental levels for the CAL Module is detailed in Table 8.

This requirement is applicable to equipment and subsystem enclosures and all interconnecting cables. The requirement is applicable as follows:

a) 2 MHz to 30 MHz Optional for Spacecraft applications

b) GLAST Transmitter frequency (TBD)

c) Delta II Launch vehicle transmitter frequency (TBD)

d) 30 MHz to 1 GHz

e) 1 GHz to 18 GHz

f) 18 GHz to 40 GHz Optional for Spacecraft applications

The Calorimeter module shall not exhibit any malfunction, degradation of performance, or deviations from unit specification, when subjected to the radiated electric fields of 20 volts/meter (modulated TBD) as specified for spacecraft applications. However, electric fields of ~ 40 Volts/meter or greater are typical for S/C and launch vehicle transmitter frequencies. Up to 30 MHz, the requirement shall be met for vertically polarized fields. Above 30 MHz, the requirement shall be met for both horizontally and vertically polarized fields. Circular polarized fields are not acceptable.

The test procedure for performing Radiated Susceptibility testing (Electric Field) may be found in Section (5.19.3) of MIL-STD-461E.

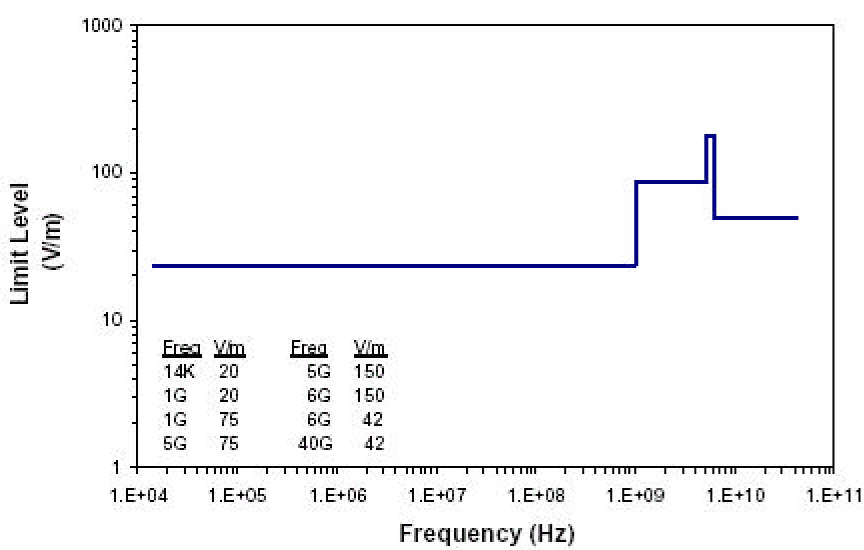


Figure 23: Instrument Launch Electric Field Radiated Susceptibility Survival Limit (RS103)

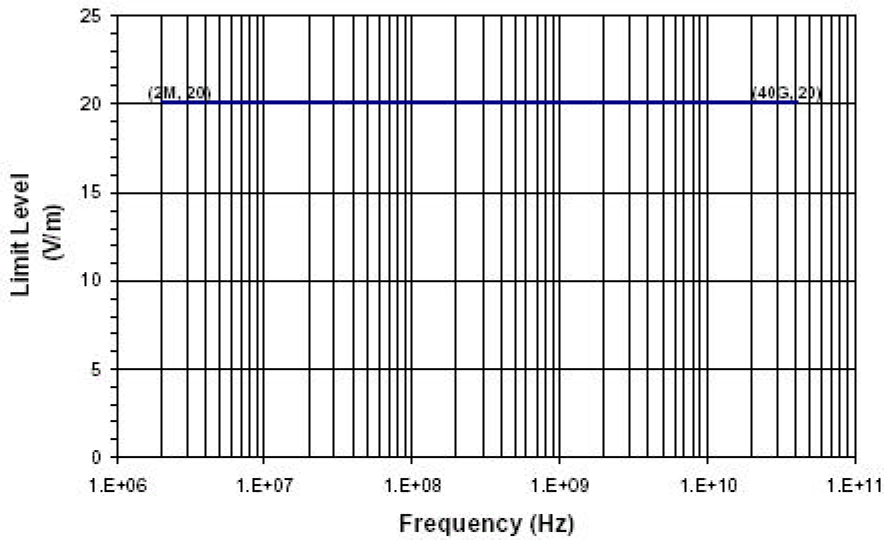


Figure 24: Instrument Perform Electric Field Radiated Susceptibility Performance Limit (RS103)

Table 8: GLAST Spacecraft Generated RF Sources (TBR)

Transmitter	**Band**	**Center Frequency (GHz)**	**Modulation Type**	**Bandwidth (MHz)**	**Volts/m @ Instrument (E_{Peak})**
	USB	2.2875	(TBD)	2.112 (2)	(TBD)
	USB	2.2875	(TBD)	2.112 (2)	(TBD)
	X	7.812	(TBD)	TBD (1)	(TBD)
	X	8.212	(TBD)	375 (1)	(TBD)

(1) Width of main lobe of the transmitter spectrum (null to null).

(2) TBD

5.5.3 ESD Compatibility

ESD compatibility tests will be conducted on each subsystem electrical component at the qualification level. These tests are to ensure proper grounding of the electrical/electronics assemblies with the LAT structure.

The CAL Module Grounding and Shielding Plan [LAT-SS-00272-D1] shall address specific bonding resistance levels and level of shielding required to ensure the CAL modules are immune to the hazards of electro-static discharge potentials.

5.5.4 Magnetic Properties Test

Magnetic property requirements for CAL Module Subsystems are based on magnitudes which, taken individually, are not expected to affect the operation of other components or, taken collectively, are not expected to affect the LAT instrument and spacecraft operation or performance. These magnitudes are given in terms of dipole moments for specified conditions, expressed as test requirements. Measurements shall be made at a distance of 3 times the maximum linear dimension of the test article in order to minimize the influence of localized magnetic sources. [Some discussion as to moving this test after vibration testing is needed….magnetic field lines from shaker table more than likely to alter the magentic profile of the test article]

The following shall describe the tests and measurement requirements for Magnetic Properties.

5.5.4.1 INITIAL PERM TEST

The maximum dc magnetic field produced by the component (non-operating) shall not exceed 0.2 A-m^2.

5.5.4.2 PERM LEVELS AFTER EXPOSURE TO MAGNETIC FIELDS

The maximum dc magnetic field produced by the component after exposure to magnetic filed test levels of 15 x 10^{-4} tesla shall not be exceed 0.1 A-m^2.

5.5.4.3 PERM LEVELS AFTER EXPOSURE TO DEPERM TEST

The maximum dc magnetic field produced by the component after exposure to magnetic field deperm levels of 50 x 10^{-4} tesla shall not exceed 0.1 A-m^2.

5.5.4.4 INDUCED MAGNETIC FIELD MEASUREMENT

The induced magnetic field of the component, while the component is turned off and exposed to magnetic test level of 0.6 x 10^{-4} tesla shall not exceed 0.02 A-m^2.

5.5.4.5 STRAY MAGNETIC FIELD MEASUREMENT

The component shall not produce magnetic fields resulting from internal current flows that are in excess of 0.05 A-m^2.

5.6 Thermal Tests

5.6.1 Thermal Vacuum

The CAL EM and QM Modules shall be subjected to a thermal vacuum test with thermal cycling to the qualification levels. These modules will undergo 12 (twelve) cycles for qualification purposes. The CAL FM Modules shall undergo 4 (four) thermal vacuum cycles at the acceptance levels. At the hot and cold plateaus, a 12-hour, minimum soak at these temperatures will be demonstrated at the Qual level and a 4-hour, minum soak at these temperatures will be demonstrated at the Acceptance level. Additional tests during the TV test are outlined below:

- Turn on shall be performed once at the hot plateau and once at the cold plateau.
- CPT shall be performed at each plateau.
- Limited performance tests shall be conducted during thermal transitions in where system failures or intermittent problems are most likely to occur.

Figures 25 & 26 below shows the thermal profiles at the qualification and acceptance level for CAL Modules.

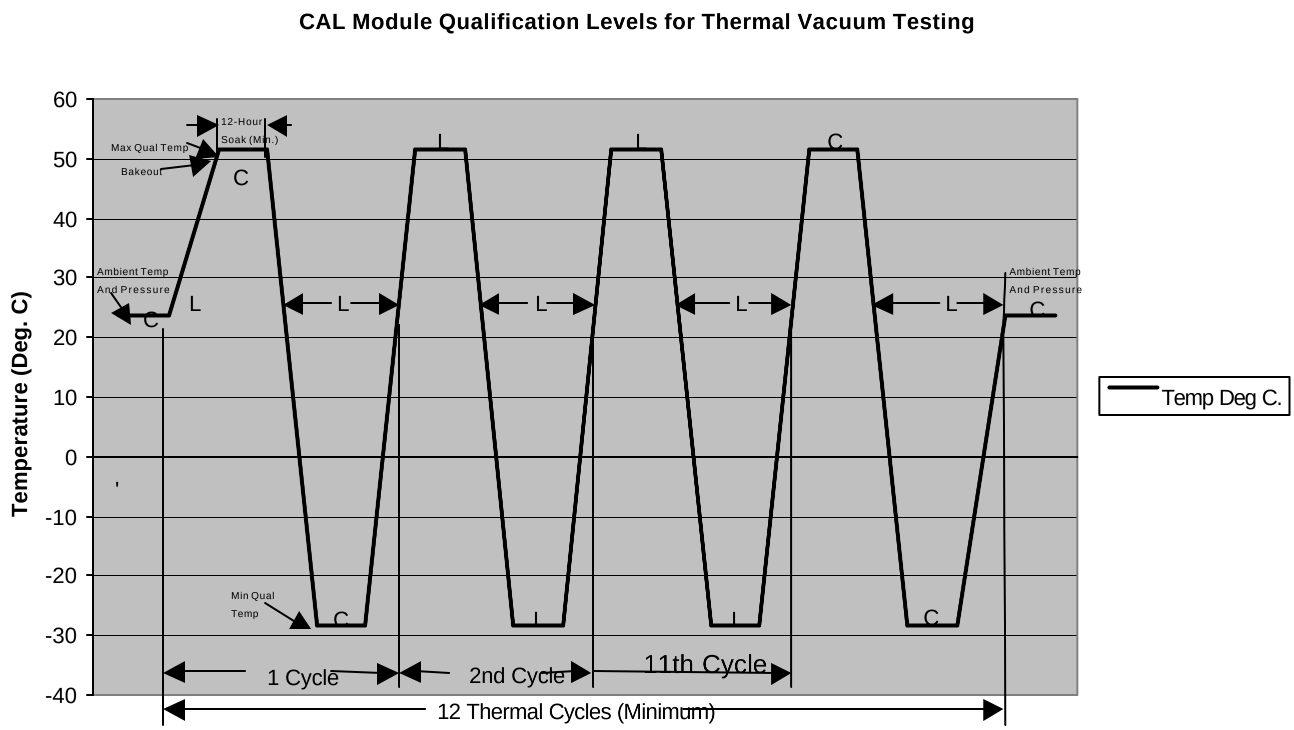


Figure 25: Thermal Vacuum Qualification Profile

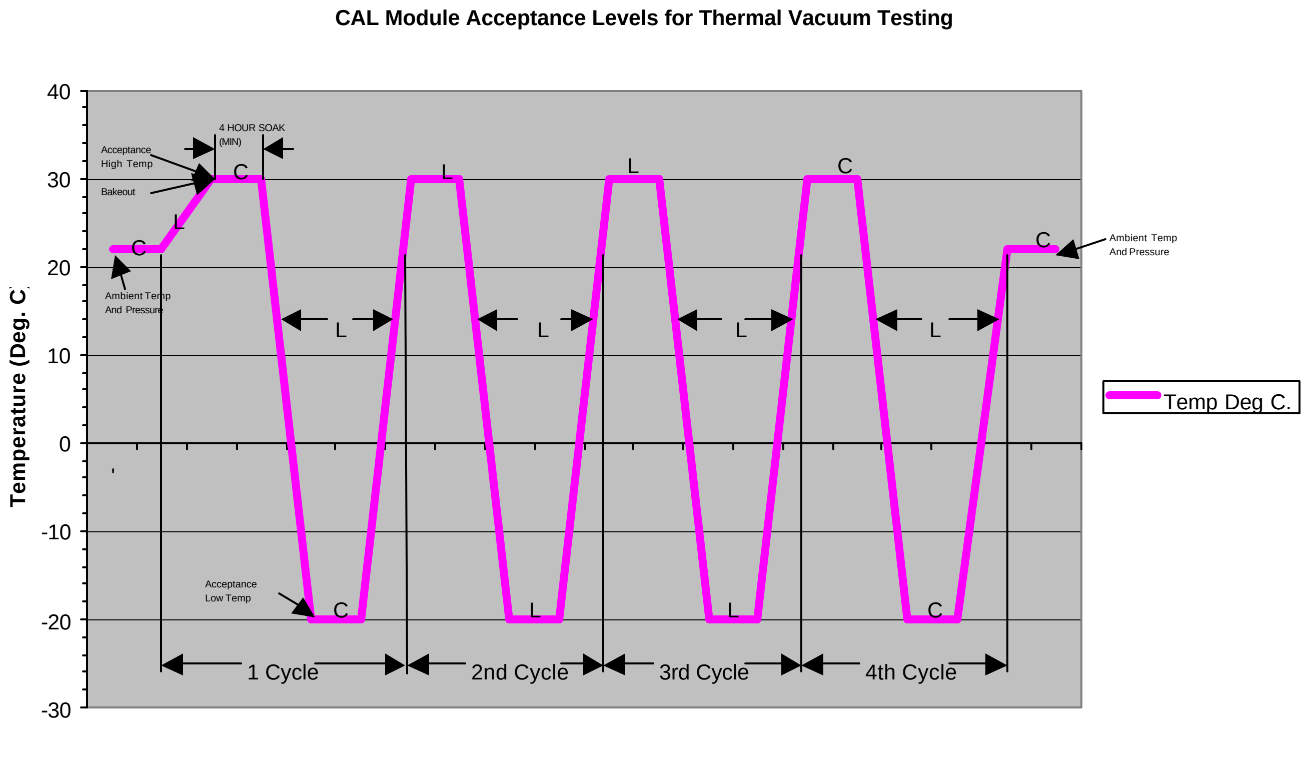


Figure 26: Thermal Vacuum Acceptance Profile

5.6.2 Thermal Cycle

Thermal cycling at ambient pressure shall be conducted at the qualification levels for the following:

- EM CDE's and AFEE Boards
- QM CDE's and AFEE Boards
- Flight CDE's and AFEE Boards

These tests may be applied to sample batches (TBD)

5.6.3 Thermal and Humidity

During the test phase of CAL component or subsystem, temperature and humidity measurements shall be recorded as part of the particular test procedure. When not in test, components, subsystem shall be stored in a controlled environment as to maintain proper temperature and humidity levels. Thermal Graph readings of temperature and humidity shall be incorporated in the qualification data package. The following table indicates operational, transport and storage requirements for CAL temperature and humidity.

Table 9: Calorimeter Modules Temperature and Humidity Requirements

Environment	**Low**	**High**	**Driving Req**
Bench test operating temperature	15°C	30°C	IRD 3.2.1.5.1
Ground storage/transport temperature	0°C	40°C	
Operating/storage relative humidity	30%	55%	LPS 3.2.1.5.2

5.6.4 Bakeout

Generally during bakeout, the thermal vacuum chamber's temperature is elevated to a level in excess of 40° C. and held there until the readings on the thermoelectric quartz crystal microbalance (TQCM) allow you to proceed. Plastics, entrained water vapour and hydrocarbons "outgas" until the rate of outgassing falls to a level depicted in the contamination control plan.

Calorimeter Vacuum Bakeout Requirements including test cables may be found in Section 9.0 of the GLAST LAT Contamination Control Plan [LAT-MD-00228].

The thermal-vacuum test fulfills the bakeout function as the first "hot" soak can function as the bakeout level. [Need to discuss if bakeout is required for the FM CAL Modules. I feel since the units will be thermal vacuum cycled at the acceptance level, there should be a bakeout incorporated in this test. However, TV at the acceptance level hot temperature is only 30°C, (86°F) and may not be high enough for a proper bakeout.]

5.6.5 Burn In

Burn in tests at the Acceptance Level high temp (+30°C) will be used to achieve 150 hours of failure free power on time prior to delivery to LAT integration on all CAL units which have been acceptance tested.

5.7 Other Tests

5.7.1 Radiation

5.7.2 Beam Tests

5.7.2.1 EM SHOWERS

5.7.2.2 HADRONS ???

5.7.2.3 HEAVY IONS

5.8 Reliability

The Calorimeter Modules shall be verified by analysis to have a probability of total failure of <0.8 %. This analysis may be found in LAT-TD-00464, GLAST LAT Calorimeter FMEA, RBD, Predictions and CIL.

5.9 Operability

The Calorimeter Modules shall be verified by analysis to prove operability with <10% loss in effective area. This analysis may be found in LAT-TBD.